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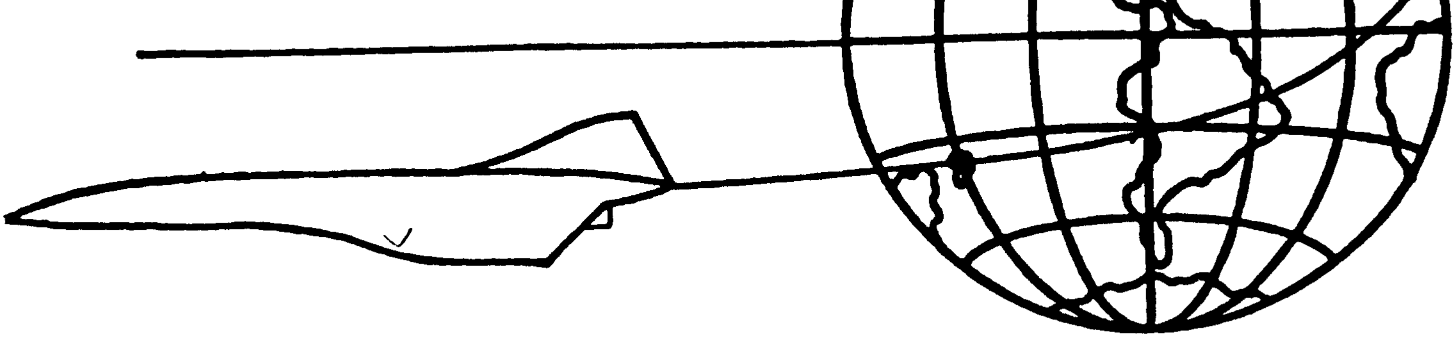

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NASA / USRA ADVANCED DESIGN PROGRAM

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CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA
AEROSPACE ENGINEERING DEPARTMENT

FINAL REPORT 1987 - 88

VOLUME IV

THE LEADING EDGE 250

OBLIQUE WING AIRCRAFT CONFIGURATION PROJECT

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14 June 1988

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LIST OF SYMBOLS

SYMBOL	DEFINITION
AR	Aspect ratio
b	Span (ft)
c	Chord (ft)
c.g.	Center of gravity (ft)
C_D	Drag coefficient
$C_{D\alpha}$	Variation of drag coefficient with angle of attack (/rad)
$C_{D\dot{\alpha}}$	Variation of drag coefficient with rate of change in angle of attack
$C_{D\delta E}$	Variation of drag coefficient with elevator angle
C_{Dq}	Variation of drag coefficient with pitch rate
C_{Du}	Variation of drag cefficient with speed
C_L	Airplane lift coefficient
$C_{L\alpha}$	Variation of lift coefficient with angle of attack
$C_{L\dot{\alpha}}$	Variation of lift coefficient with rate of change in angle of attack
$C_{L\delta E}$	Variation of lift coefficient with elevator angle
C_{Lq}	Variation of lift coefficient with pitch rate
C_{Lu}	Variation of lift coefficient with speed
$C_{l\alpha}$	Airfoil lift curve slope
$C_{l\beta}$	Variation of rolling moment coefficient with sideslip angle
$C_{l\delta A}$	Variation of rolling moment coefficient with aileron angle
$C_{l\delta R}$	Variation of rolling moment coefficient with rudder angle
C_{lp}	Variation of rolling moment coefficient with roll rate
C_{lr}	Variation of rolling moment coefficient with yaw rate
$C_{m\alpha}$	Variation of pitching moment coefficient with angle of attack
$C_{m\dot{\alpha}}$	Variation of pitching moment coefficient with rate of change of angle of attack
$C_{m\delta E}$	Variation of pitching moment coefficient with elevator angle
C_{mq}	Variation of pitching moment coefficient with pitch rate

$C_{m u}$	Variation of pitching moment coefficient with speed
$C_{n\beta}$	Variation of yawing moment coefficient with sideslip angle
$C_{n\delta A}$	Variation of yawing moment coefficient with aileron angle
$C_{n\delta R}$	Variation of yawing moment coefficient with rudder angle
C_{np}	Variation of yawing moment coefficient with roll rate
$C_{y\beta}$	Variation of side force coefficient sideslip angle
$C_{y\delta A}$	Variation of side force coefficient aileron angle
$C_{y\delta R}$	Variation of side force coefficient rudder angle
C_{yp}	Variation of side force coefficient roll rate
C_{yr}	Variation of side force coefficient yaw rate
FAR	Federal Aviation Regulation
h	Altitude (ft)
Ixx	Rolling moment of inertia (slg/ft^2)
Iyy	Pitching moment of inertia (")
Izz	Yawing moment of inertia (")
Ixy	XY product of inertia (")
Ixz	XZ product of inertia (")
Iyz	YZ product of inertia (")
L	Total lift force (lbf)
L/D	Lift to drag ratio
M	Mach number
Q	Heat flux (Btu/h ft °F)
S	Surface area (ft^2)
T	Thrust (lbf)
V	Velocity (fps)
W	Weight (lbs)
WE	Empty weight (lbs)
WF	Fuel weight (lbs)
W_{GTO}	Gross takeoff weight (lbs)
X	Longitudinal distance (ft)
Z	Vertical distance (ft)

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SUMMARY

The Leading Edge 250 is a High Speed Civil Transport capable of travelling at a speed of Mach 4 with 250 passengers. With a 6,500 nautical mile range, it can fly its passengers from Los Angeles to London within three hours, an exciting change from the usual 14 hour trip.

However, its innovation lies within its use of the unconventional oblique wing to provide efficient flight at any Mach number. Wave drag is kept to a minimum at high speed, while high lift is attained during critical takeoff and landing maneuvers, by varying the sweep angle accordingly.

It is time to begin shrinking the world...

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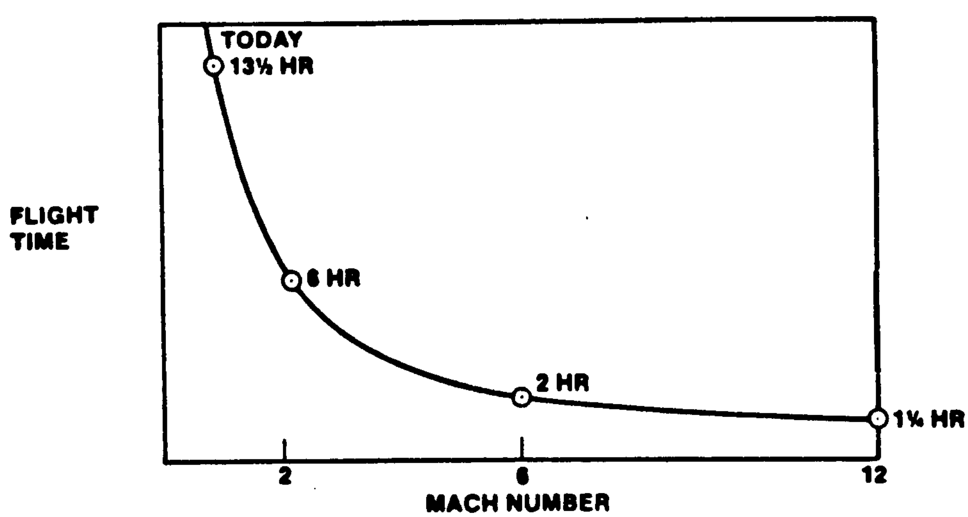
1.0 INTRODUCTION

Supersonic and hypersonic transportation for the general public has been a major consideration in industry for many years. At today's subsonic speeds, a trip to Europe can take on the average up to 13 ½ hours. It is common knowledge that people are reluctant to travel even when the planned trip is expected to take over just a few hours. And though the Concorde is capable of more than twice the cruise speed of most modern transports, it fails to attract customers due to its higher fares, which, for transatlantic flights, can reach more than 30 percent over subsonic first class rates.

Fueled by the impatience of the frequent flyer, and the challenge faced by the engineer to design on technology's edge, there is presently a drive to produce an aircraft capable of shrinking travel time to Europe and the Pacific Basin down to a minimum. For a 6,500 nautical mile range, a distance that would satisfy over 90% of today's travellers' needs, Figure 1.1 shows that an aircraft cruising at a Mach 2 would cut the 13 ½ hour travel time of modern transports in half. A Mach 5 aircraft

FIGURE 1.1 FLIGHT TIME



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could further shrink that time to almost three hours. This alone should make a High Speed Civil Transport appealing to anyone who travels by air.

Improvements in technology in recent years have brought the reality of an HSCT within reach of the capabilities of the world's aerospace industries. The proposed Leading Edge 250 design presented hereafter offers one possible route to meeting the mission requirements of a High Speed Civil Transport using existing technology while remaining reasonable in cost and concept. The design constraints produced by the design team for the Leading Edge 250 HSCT are presented in Table 1.1.

TABLE 1.1 REQUEST FOR PROPOSAL

RANGE	6,500 nautical miles
CRUISE SPEED	Mach 3 - 6
CRUISE ALTITUDE	80,000 to 100,000 feet
PAYLOAD	250 people/(200 lb per person)
MAXIMUM FIELD LENGTH	11,500 feet
MAXIMUM TAKEOFF WEIGHT	1,000,000 lb
NOISE	< 1.0 psf overpressure
STABILITY	FAR (sec. 25)
TURNAROUND TIME	1 hour or less

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2.0 CONFIGURATION SELECTION

Through studies of the performance of various planform configurations at high Mach numbers, it became evident that oblique wing planforms tend to possess considerably less wave drag than more conventional symmetrically swept wings (Reference 1). The capability of variable geometry of the oblique wing also allows it to be swept at an optimum angle for different Mach numbers providing more efficient flight than can be obtained from conventional fixed wing configurations. Equivalently, at subsonic speeds, when the wing is unswept, an oblique wing aircraft requires less takeoff distance, has a higher climb rate, and therefore produces less noise than conventional supersonic aircraft (Reference 2). It also has the ability to cruise efficiently at reduced speeds. The sonic boom produced by an oblique wing was also found to be less than that of conventional designs due to the fact that the lift and volume of the wing is distributed over a greater longitudinal distance (Ref. 1 & 2).

Because of the superior efficiency and performance of the oblique wing at varying Mach numbers, over conventional arrow shaped supersonic wings, it was chosen as the configuration basis. And in order to begin preliminary design work on the Leading Edge 250 HSCT, a service ceiling and cruise Mach number were required. From the ranges given in the RFP of Table 1.1, a maximum cruise altitude of 100,000 feet and a design cruise Mach number of 4 were chosen.

Table 2.1 summarizes the advantages of the oblique wing

planform over conventional configurations, and introduces the more prominent disadvantages.

TABLE 2.1 OBLIQUE WING CHARACTERISTICS

ADVANTAGES:

- Lower Wave Drag at Supersonic and Transonic Speeds
- Lower Structural Weight
- Optimum Sweep Provides Efficient Flight at all Mach Numbers
- Unswept Wing Offers Reduced Takeoff Distances
- Reduced Takeoff Distances Provide Less Takeoff Noise
- Lower Sonic Boom Intensity Due to Lift Distribution Over Greater Length
- Tendency to Roll Out of Right Banks

DISADVANTAGES:

- Strong Pitch-to-Roll Coupling
- Strong Pitch-to-Sideforce Coupling
- Tendency to Roll Into Left Banks

3.0 CONFIGURATION DESCRIPTION

The Leading Edge 250 HSCT shown in Figure 3.1, is comparable in size and weight to a Boeing 747-100B commercial passenger transport. It carries 250 passengers, as the name implies, and a crew of 10, including 8 attendants and 2 pilots. Some of the key features of the Leading Edge 250 HSCT configuration are:

An oblique wing planform possessing a maximum rotation angle of 80 degrees.

A NACA 64-206 airfoil for the wing ($C_{l\alpha}$ = 0.110/deg), and NACA 0006 airfoils for the horizontal and vertical tails.

A cruise Mach number of 4 with a maximum capability of Mach 5.

A gross takeoff weight of 766,824 lbs. and an empty weight of 430,824 lbs.

Differential elevators for roll control in subsonic flight; assisted by 4 spoilers, located on the top and bottom surfaces of the engine nacelles, in supersonic flight.

A blunt nose cone with a 20° semivertex angle which produces a mach cone that lies beyond the forward wingtip at any given wing rotation angle.

Double slotted flaps with a maximum deflection angle of 70°.

Engines located aft of the passenger cabin, producing less noise inside aircraft.

The Leading Edge's fuselage dimensions are given in Table 3.1.

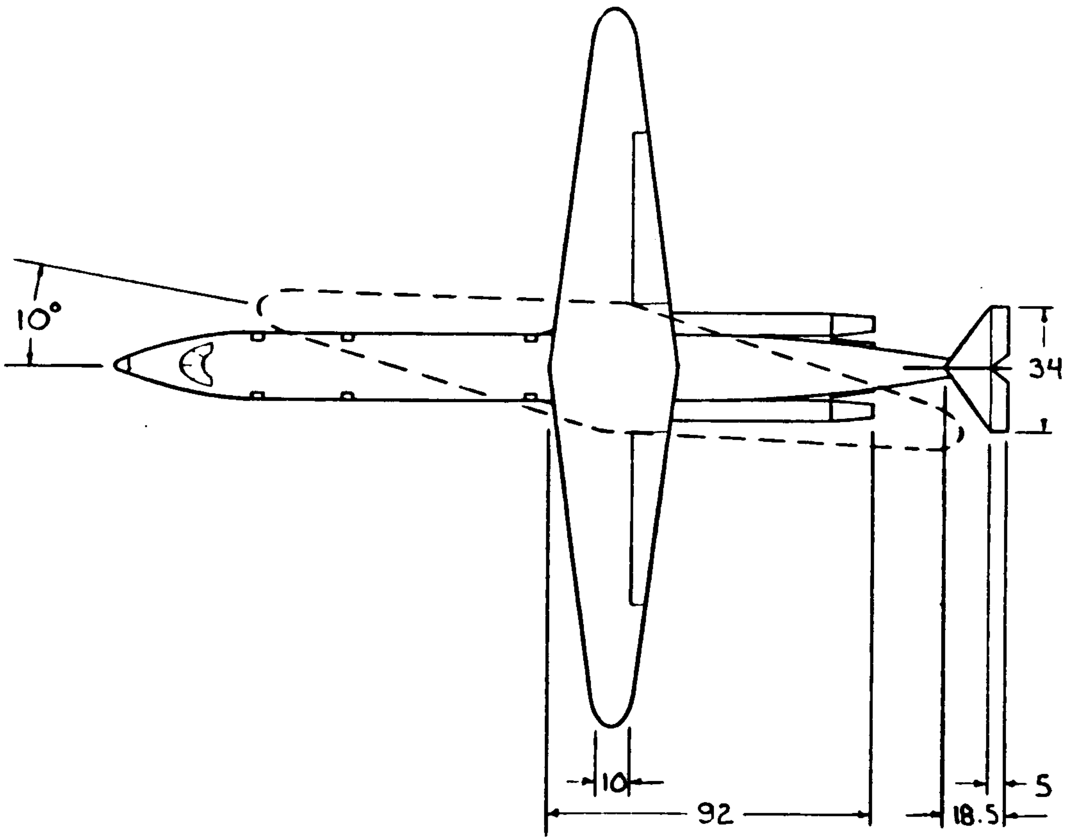
TABLE 3.1 **FUSELAGE DATA**

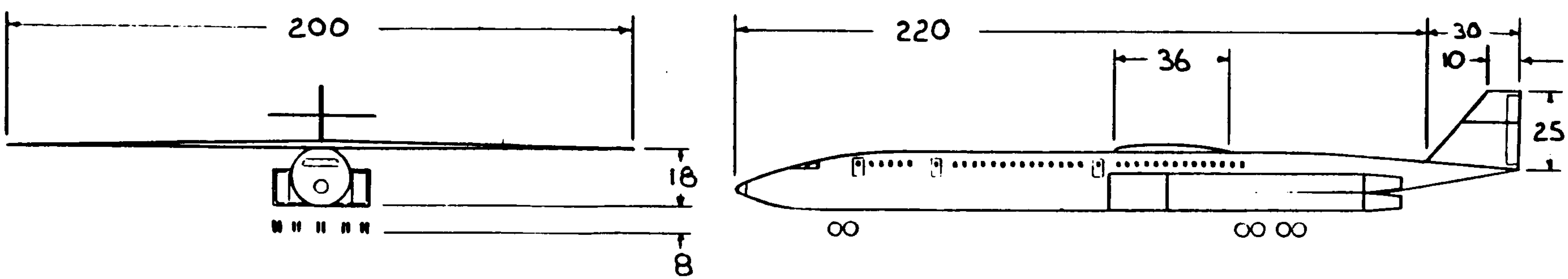
LENGTH	250 ft
MAXIMUM OUTSIDE CABIN DIAMETER / NO ENGINES	18 ft
MAXIMUM WIDTH / WITH ENGINES	30 ft
MAXIMUM HEIGHT / NO VERTICAL TAIL	28.16 ft
MAXIMUM HEIGHT / WITH VERTICAL TAIL	46 ft

FIGURE 3.1
LE 250
THREE VIEW
DRAWING

W_{GTO}	=	766,824 lbs
S_W	=	4,606 ft^2
$\bar{c}_W$	=	23 ft
AR_W	=	8.7
S_H	=	400 ft^2
$\bar{c}_H$	=	11.75 ft
AR_H	=	2.89
S_V	=	500 ft^2
AR_V	=	1.25

SCALE: 0' 25' 50'





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Dimensions for the lifting surfaces and the vertical tail are presented in Table 3.2.

TABLE 3.2 LIFTING SURFACE/TAIL DATA

	WING	HORIZONTAL TAIL	VERTICAL TAIL
AREA	4,606 ft^2	400 ft^2	500 ft^2
SPAN	200 ft	34 ft	25 ft
MEAN CHORD	23 ft	11.75 ft	20 ft
ROOT CHORD	36 ft	18.50 ft	30 ft
TIP CHORD	10 ft	5 ft	10 ft
ASPECT RATIO	8.68	2.89	1.25
L.E. SWEEP	7.5°	38.45°	38.5°
c/4 SWEEP	3.25°	30.77°	30.5°
c/2 SWEEP	0°	21.63°	22.0°
DIHEDRAL	0°	0°	N/A
FLAP CHORD RATIO			0.30
DIFFERENTIAL ELEVATOR CHORD RATIO			0.43
RUDDER CHORD RATIO			0.20

4.0 MASS PROPERTIES

This chapter presents the preliminary weight estimation of the Leading Edge 250 HSCT, as well as a more detailed weight analysis which sums up the weights of airplane's components. As a result of weight estimation, other mass properties can be obtained sequentially.

4.1 PRELIMINARY WEIGHT ESTIMATION

The Leading Edge 250 has been designed to meet the RFP and the mission profile presented in Figure 4.1. The mission profile shows that the flight is broken up into several regimes, which were used in a fuel fraction analysis (Reference 3) to define the preliminary configuration. The fuel fraction analysis was utilized to yield the following preliminary weight parameters:

Payload weight,	WP	=	53,505 lbs
Empty weight,	WE	=	253,200 lbs
Fuel weight,	WF	=	268,737 lbs
Take-off weight,	WTO	=	575,454 lbs

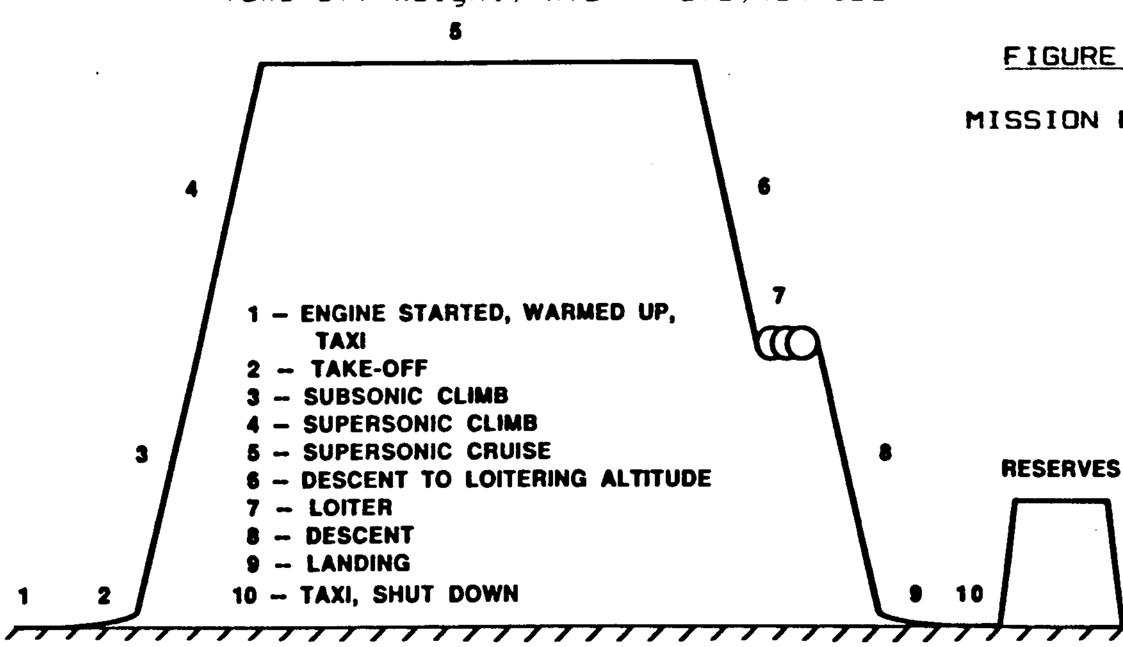

FIGURE 4.1

MISSION PROFILE

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Table 4.1 shows the detail fuel fraction analysis results. The oblique wing design was found to have a lighter weight than other HSCT designs in the preliminary weight analysis. This is due to the advantages in aerodynamics the oblique wing configuration has over other configurations.

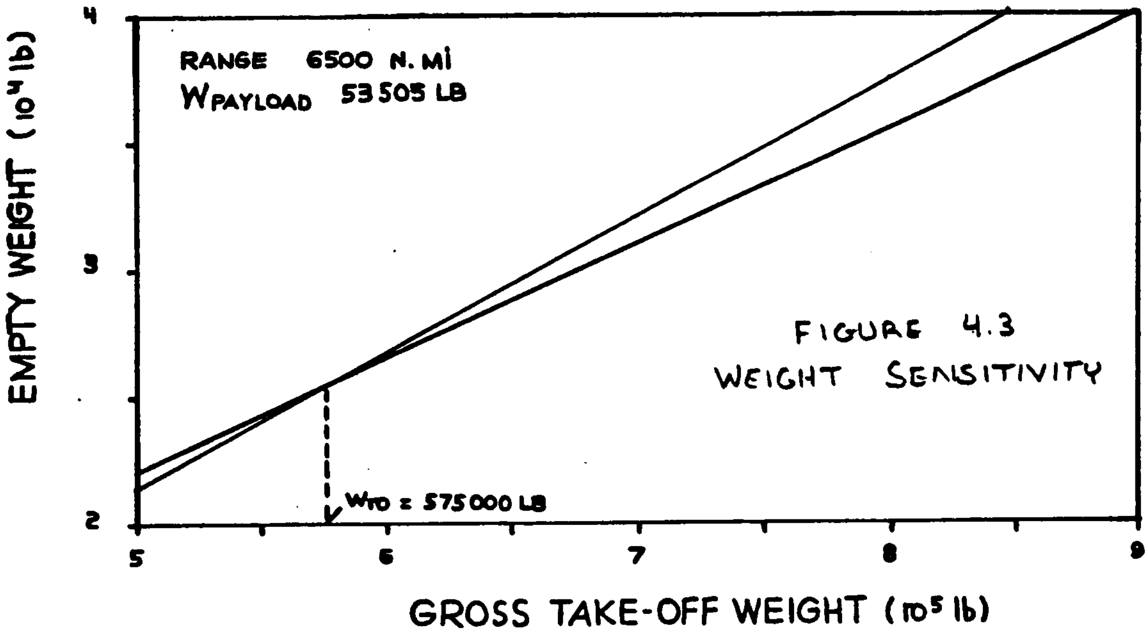
TABLE 4.1 PRELIMINARY WEIGHT ESTIMATION

PAYLOAD WEIGHT:	W_{PL} = (170 lbs/per + 35 lbs bag./per) *(250 pass. + 8 crew + 3 cockpit)	
	W_{PL} = 53,505 lbs	
FUEL WEIGHT:	1. ENGINE START, WARM UP	W_1/W_{TO} = 0.990
	2. TAXI	W_2/W_1 = 0.995
	3. TAKEOFF	W_3/W_2 = 0.995
	4. CLIMB (C_j = 1.5, L/D = 7, RC_{ave} = 2,000 fpm)	W_4/W_3 = 0.840
	5. CRUISE (C_j = 1.5, L/D = 7, RC_R = 6,500 n. mi.)	W_5/W_4 = 0.760
	6. LOITER (C_j = 1.5, L/D = 9, T_{loiter} = 30 min)	W_6/W_5 = 0.920
	7. DESCENT	W_7/W_6 = 0.985
	8. LANDING	W_8/W_7 = 0.995
	9. TAXI,SHUT DOWN	W_9/W_8 = 0.995
	TOTAL:	W_9/W_{TO} = 0.561

W_{MF} = (1-0.561)W_{TO} = 0.439 W_{TO}

RESERVED/TRAPPED FUEL WEIGHTS:	W_{RF} = 0.050 W_F
	W_{TF} = 0.010 W_F
TOTAL FUEL WEIGHT:	$W_F = W_{MF} + W_{RF} + W_{TF}$
	$= 0.439\ W_{TO} + 0.050\ W_F + 0.010\ W_F$
	$W_F = 0.467\ W_{TO}$
EMPTY WEIGHT:	$W_E = 0.440\ W_{TO}$
PAYLOAD WEIGHT:	$W_{PL} = 0.093\ W_{TO}$
	W_{TO} = 53,505 lbs/0.093 = 575,454 lbs

Figure 4.2 shows the sensitivity of empty weight to take-off weight.

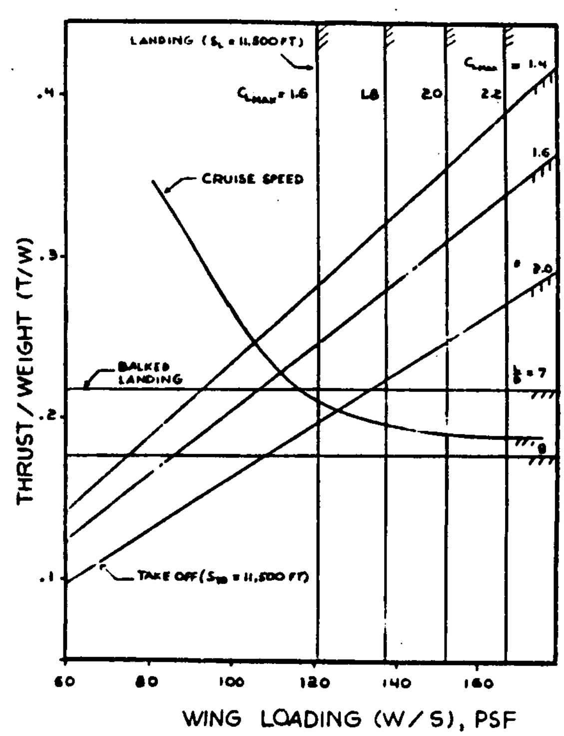


4.2 INITIAL PERFORMANCE SIZING

Using the initial weights, a preliminary performance sizing analysis was performed. This analysis was done to satisfy the performance required either in the RFP or FAR Part 25. From the study of existing oblique wing designs and concepts, an aspect ratio of 10 was initially chosen to calculate the cruise speed requirement of Mach 4 and 5. Figure 4.3 is the resulting sizing diagram of these criteria: take-off field length, landing field length, balked landing, and supersonic cruise speed.

FIGURE 4.3

SIZING CHART



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From the diagram in Figure 4.3, the following design parameters were selected to initially size the general shape of the Leading Edge 250:

$T/W = 0.28$ $T = 161{,}152$ lbs $CLMAX(TO) = 2.0$

$W/S = 166.0$ $S = 3500\ ft^2$ $CLMAX(L) = 2.2$

4.3 COMPONENT WEIGHTS

The component weights for the Leading Edge 250 were estimated using equations from Reference 3. The resultant weights for the aircraft are presented in Table 4.2.

TABLE 4.2

COMPONENT WEIGHTS

Component	Weight lbs	X (ft)	Z (ft)
Wing	163,838	134	40
Fuselage	163,918	125	30
Horizontal Tail	4,117	226	35
Vertical Tail	2,080	239	55
Nose Landing Gear	3,961	63	27
Main Landing Gear	11,881	160	27
Engines	35,312	215	26
Duct Weight	3,380	170	28
Bladder Cell 1	1,900	135	25
Bladder Cell 2	2,528	82	25
Bladder Cell 3	2,528	107	25
Bladder Cell 4	2,528	134	25
Fuel Systems Backing	2,290	109	15
C.G. Control	533	143	36
Engine Controls	257	210	27
Engine Starting Systems	338	205	27
Hydraulics 1	2,500	63	24
Hydraulics 2	2,500	160	50
Controls 1	1,191	147	40
Controls 2	1,000	235	55
Flight Instruments	77	20	30
Engine Instr. Indicators	37	33	34
Misc. Indicators	110	33	34
Electrical Systems 1	1,000	29	27
Electrical Systems 2	1,812	150	30
Electrical Systems 3	1,812	200	28
Flight Deck Seats	165	38	40
Passenger Seats 1	1,089	56	40
Passenger Seats 2	3,459	94	40
Passenger Seats 3	3,459	148	40
Lavatories & Galleys 1	195	44	40
Lavatories & Galleys 2	195	69	40
Lavatories & Galleys 3	292	120	40
Lavatories & Galleys 4	292	174	40
Oxygen Systems	355	103	43
Windows 1	116	57	40
Windows 2	290	94	40
Windows 3	290	148	40
Anti-Icing 1	1,327	129	55
Anti-Icing 2	1,327	221	60
Air Conditioning	3,001	110	43
Empty Weight	430,824		
Fuel 1	225,160	107	25
Fuel 2	56,040	197	27
Passengers 1	6,120	53	40
Passengers 2	19,040	94	40
Passengers 3	19,040	148	40
Baggage	11,600	35	30
Takeoff Weight, W_{TO}	766,824		

4.4 BALANCE

Figure 4.4 gives a sideview of locations of the component centers of gravity for the Leading Edge 250. The Table 4.2 also presented the aircraft's balance statements, and Figure 4.5 below is the related c.g. travel diagram. At maximum take-off weight, the Leading Edge 250 has a maximum c.g. travel of 5.4 ft in flight. This is 15% of root chord.

LEGEND

1. Nose Gear
2. Main Gear
3. Landing Gear Hydraulics
4. Avionics
5. Baggage
6. Fuel
7. Inlets
8. Engines
9. Indicators
10. Food Provisions
11. Doors
12. Passengers, Galleys, Windows
13. Air Conditioning Units
14. Anti-Icing
15. Wing
16. Control Systems Hydraulics
17. Vertical Tail
18. Horizontal Tail
19. Fuselage

FIGURE 4.4 C.G. LOCATIONS

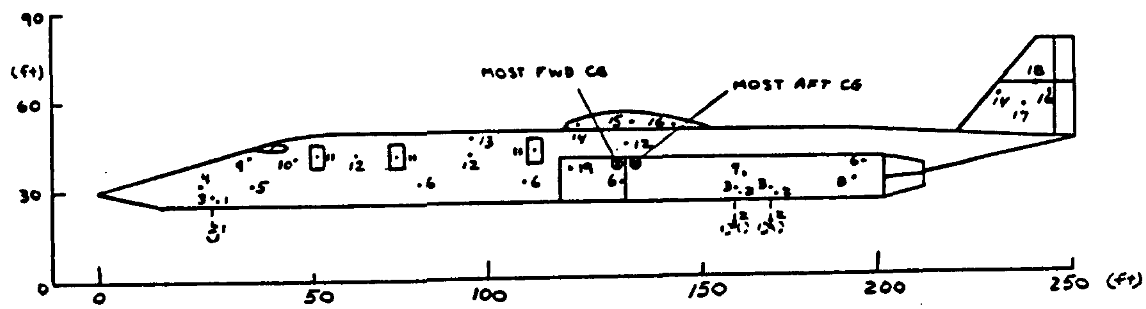
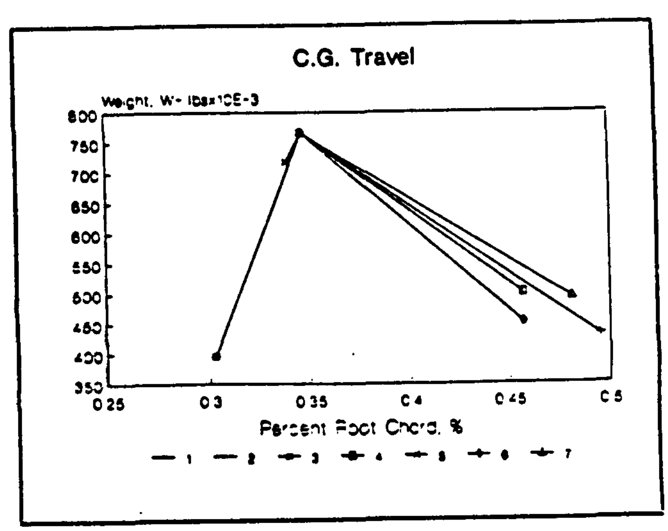


FIGURE 4.5 C.G. TRAVEL

LEGEND

1. Full Takeoff
2. All Empty
3. All Empty
No Engines
4. Full of People
5% Fuel Remaining
5. People in First Class
Section Only
Full of Fuel
6. People in First Class
Section Only
5% Fuel Remaining
7. People in Second and
Third Sections Only
5% Fuel Remaining



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4.5 MASS MOMENTS OF INERTIA

The Leading Edge 250 was broken into 59 components to allow for an inertia estimation. Due to the configuration of the aircraft, the inertias are very dependent on the wing sweep angles. The following figures present the inertias estimated as functions of sweep angles and fuel remaining. For total takeoff weight and no wing sweep, the values are:

I_{xx}= 13,607,403 slugs-ft^2	I_{xz}= 3,106,076 slugs-ft^2
I_{yy}= 49,893,176 slugs-ft^2	I_{xy}= 0
I_{zz}= 61,416,125 slugs-ft^2	I_{yz}= 0

Additional inertia information with respect to percent fuel in the aircraft is given in Figures 4.6, .7, .8 and .9.

INERTIA VARIATIONS

FIGURE 4.6

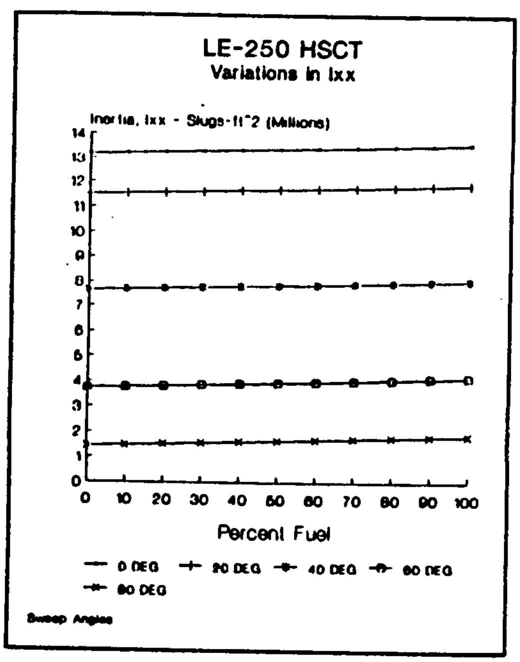
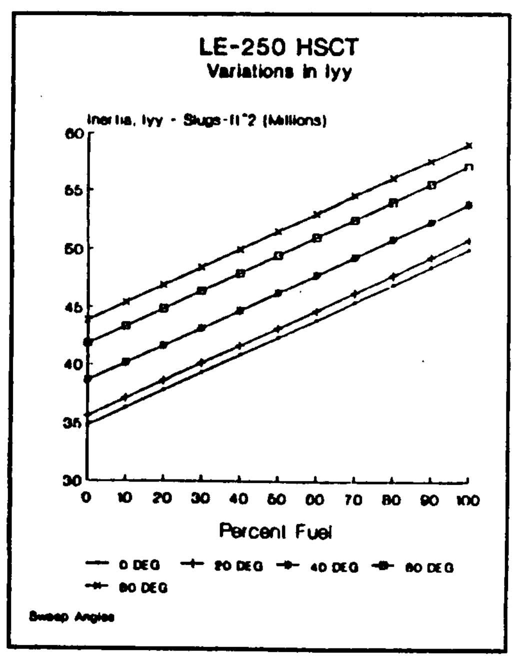


FIGURE 4.7



INERTIA VARIATIONS

FIGURE 4.7

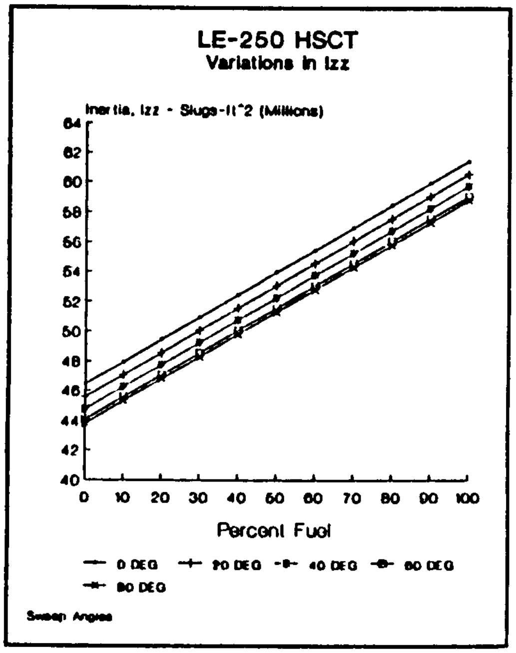
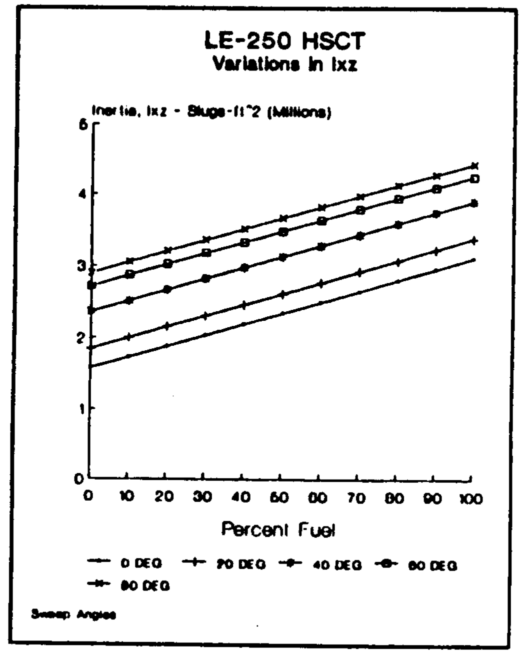


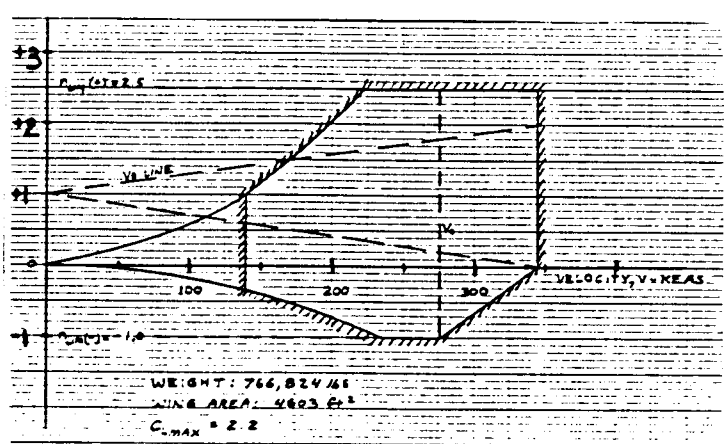
FIGURE 4.8



4.6 VELOCITY-LOAD LIMITATIONS

The Leading Edge 250 was designed to meet FAR Part 25 limitations. Figure 4.10 shows the velocity-load diagram. Due to its weight and the cruise altitude, the Leading Edge 250 is not gust sensitive. It is designed to meet the minimum FAR requirements with a positive limit load factor of 2.5 and a negative limit load factor of -1. A factor of safety of 1.5 was used to determine the ultimate load factors (3.75 and -1.5).

FIGURE 4.10 V-n DIAGRAM



5.0 AERODYNAMICS

The aerodynamic efficiency of the oblique wing design of the Leading Edge 250 is higher than that of other configurations due to its ability to adapt to the air flow at various speeds.

5.1 WING ROTATION

Although the oblique wing design already has the advantages of higher lift and lower drag than most of the other HSCT designs, the wing of Leading Edge 250 rotates at a rate that will keep itself within the strong mach cone generated from the nose of the aircraft. Figure 5.1 indicates this relationship.

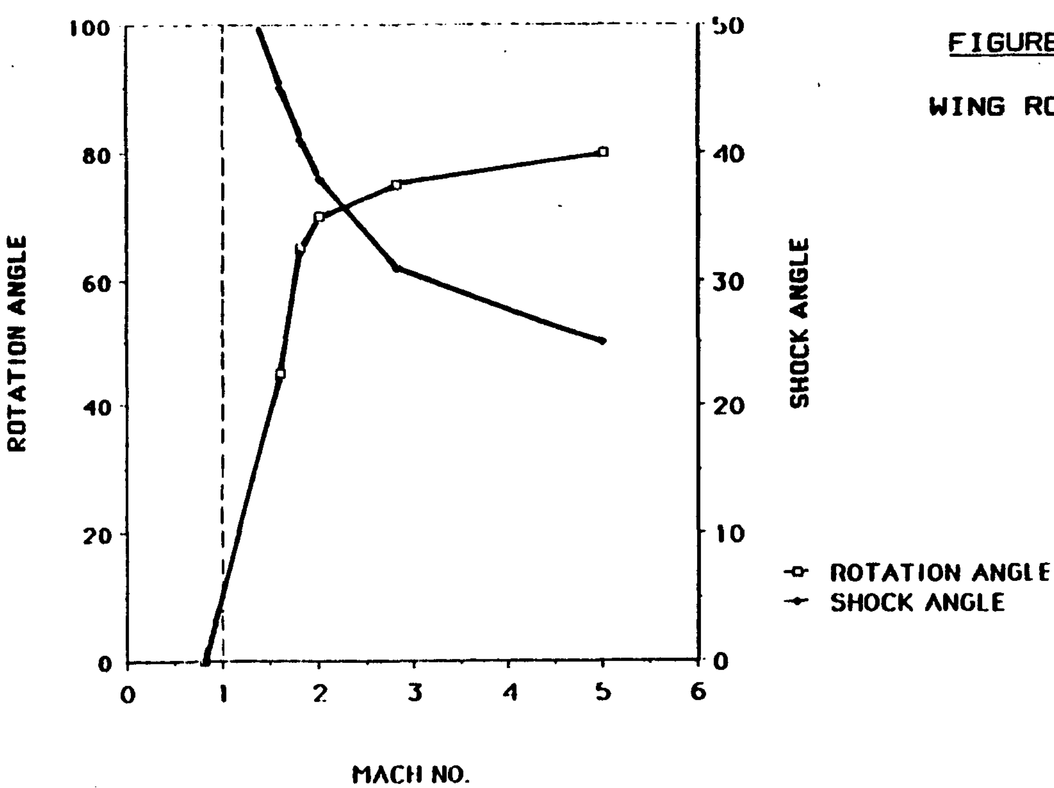


FIGURE 5.1

WING ROTATION

The result is a lower wave drag, but more important, by keeping the wing from sticking out of the nose mach cone, the existing problem of stability and control in the supersonic range will remain within a controllable envelope.

5.2 WING PLANFORM AND AIRFOIL SELECTION

The wing of Leading Edge 250 was designed to be simple for the ease of manufacture, yet would yield a high efficiency in performance. The general planform was selected from studies of previous oblique wing designs such as NASA AD-1 and the first generation supersonic transport (Ref 2). The aspect ratio of the wing was initially chosen as 10, but was later changed to 8.68 due to other constraining factors.

Since the Leading Edge 250 spends a large portion of its flight at supersonic speeds, the airfoil was chosen to be thin. The airfoil chosen is the NACA 64-206. This airfoil gives sufficient lift coefficients for all mission regimes with a maximum value of 2.2. The NACA 64-206 in the supersonic range is transformed into an extremely thin airfoil due to the rotation of the wing, and the length of the chord the flow "sees".

At cruise, the lift generated includes contributions from fuselage and engine nacelles which provide about fifty percent of the total lift; the wing provides the remaining portion. The coefficient of lift for the fuselage and nacelles is 0.104. The body lift is calculated using simple impact theory.

5.3 DRAG DETERMINATION

The calculation of values for the drag polars of the Leading Edge 250 was performed using the component drag method in Reference 3. Figure 5.2 gives the zero-lift drag component of the airplane drag coefficients at various speeds. During the transonic regime, the drag is much lower than conventional aircraft.

FIGURE 5.2

ZERO-LIFT DRAG

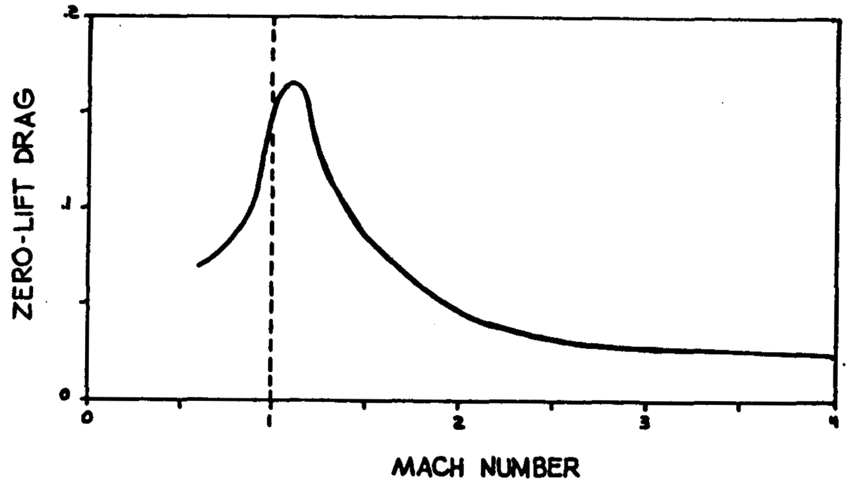
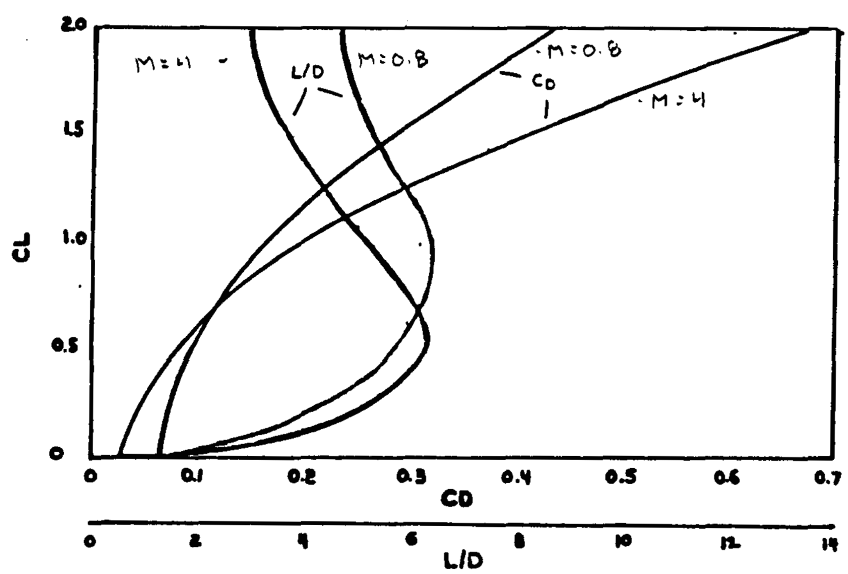


Figure 5.3 shows the drag polars for subsonic climb or loiter (M = 0.8) and supersonic cruise (M = 4.0). Lift to drag ratios resulted from the calculations are also presented.

FIGURE 5.3

DRAG POLARS



6.0 STABILITY AND CONTROL

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Because of the difficulty in calculating stability and control derivatives for the oblique wing at all possible wing rotation angles, a single subsonic Mach number was chosen for the stability analysis. A Mach number of 0.8 was used with methods presented in Reference 4 for stability calculations. This Mach number was chosen due to the fact that it is the fastest speed at which the aircraft travels before the oblique wing begins to rotate. A dynamic pressure ratio of 0.95 for both the horizontal and vertical tails was assumed, and calculations were for power off flight and no flap deflection. Table 6.1 lists the resultant stability and control derivatives, all which have met FAR Part 25 requirements.

TABLE 6.1 SUBSONIC STABILITY AND CONTROL DERIVATIVES

LONGITUDINAL		LATERAL	
$C_{L\alpha}$ =	7.646 /rad	$C_{y\beta}$ =	-0.468 /rad
$C_{m\alpha}$ =	-0.106 /rad	$C_{l\beta}$ =	0.035 /rad
$C_{D\alpha}$ =	0.116 /rad	$C_{n\beta}$ =	0.098 /rad
C_{Lu} =	0.520	C_{yp} =	0.007 /rad
C_{mu} =	0.036	C_{lp} =	-1.542 /rad
C_{Du} =	0.088	C_{np} =	-0.178 /rad
C_{Lq} =	5.549 /rad	C_{yr} =	0.260 /rad
C_{mq} =	-15.112 /rad	C_{lr} =	0.065 /rad
C_{Dq} =	0	C_{nr} =	-0.448 /rad
$C_{L\dot{\alpha}}$ =	5.257 /rad	$C_{y\delta A}$ =	0
$C_{m\dot{\alpha}}$ =	-6.213 /rad	$C_{l\delta A}$ =	0.114 /rad
$C_{D\dot{\alpha}}$ =	0	$C_{n\delta A}$ =	-0.006 /rad
$C_{L\delta f}$ =	1.128 /rad	$C_{y\delta R}$ =	0.148 /rad
$C_{m\delta f}$ =	0	$C_{l\delta R}$ =	-0.002 /rad
$C_{D\delta f}$ =	0	$C_{n\delta R}$ =	-0.078 /rad
C_{Lih} =	0.328 /rad	$C_{Ty\beta}$ =	0
C_{mih} =	-1.540 /rad	$C_{lT\beta}$ =	0
C_{Dih} =	0	$C_{nT\beta}$ =	0
$C_{L\delta E}$ =	0.158 /rad		
$C_{m\delta E}$ =	-0.731 /rad		
$C_{D\delta E}$ =	0		

A stability and control analysis for supersonic flight was not performed due to knowledge of inherent instability problems with the oblique wing at high rotation angles. Recall that the Leading Edge 250's oblique wing begins to rotate at a Mach number of 0.8, and is swept already to 70° at Mach 2. The NASA Ames Research Center, Moffet Field and Dryden Flight Research Facility have tested a prototype oblique wing aircraft, the AD-1, and have uncovered the following instability problems (Reference 5). Oblique wing aircraft possess considerable pitch-to-roll and pitch-to-sideforce cross couplings, and coupling in left and right turns. All of these coupling effects are functions of Mach number, angle of attack, and wing rotation.

With the right wing swept forward, the pitch-to-roll coupling causes the aircraft to roll to the right when it pitches up, and to roll to the left when the aircraft pitches down. The pitch-to-sideforce coupling causes the aircraft to experience a very large sideforce when performing an abrupt pitch maneuver. Oblique wing aircraft were also found to want to roll into left bank turns and out of right bank turns. These effects become worse with increasing wing rotation angles.

Though these stability problems are quite pronounced, it has been shown that through use of computer stability control, programmed with the right decoupling control laws, oblique wing aircraft can be made stable. In addition, as large as the Leading Edge 250 HSCT is, it will probably never perform abrupt maneuvers as did the AD-1 during its testing, and should respond much slower to coupling effects due to its greater inertia.

7.0 PROPULSION SYSTEM

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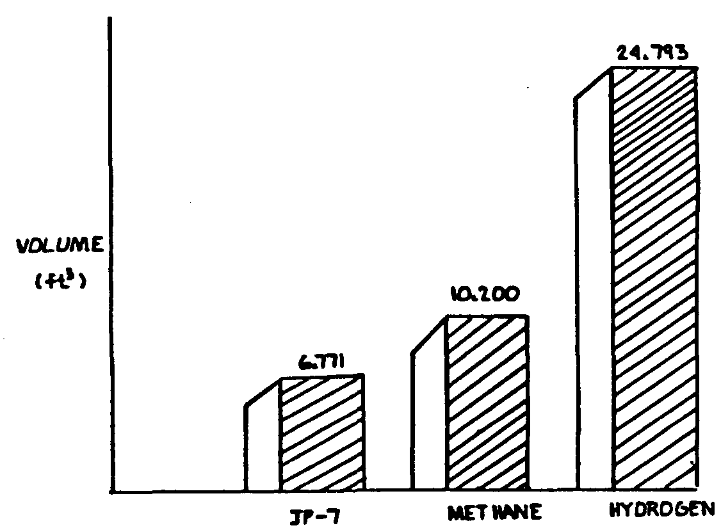
Because the Leading Edge 250 HSCT requires the use of an unconventional fuel, a special section on fuels is presented. The propulsion unit, inlet and nozzle are also defined in this chapter.

7.1 FUEL

The fuel chosen for the Leading Edge 250 is liquid methane. Liquid methane has a heat of combustion of 21,000 Btu/lb and a density of 28 lbs/ft^3. The other candidate fuels considered were JP-7 and Liquid Hydrogen. Liquid methane was chosen over JP-7 and liquid hydrogen for two reasons. The heat of combustion of methane is 16 percent higher than JP-7, but 58.4 percent lower than LH_2. However, even though LH_2 has a higher heat of combustion, it was not chosen due to its low density. Liquid hydrogen has a density of 4.7 lbs/ft^3. As shown in Figure 7.1, a total volume of about 24.8 thousand cubic feet would be required

FIGURE 7.1

FUEL COMPARISON

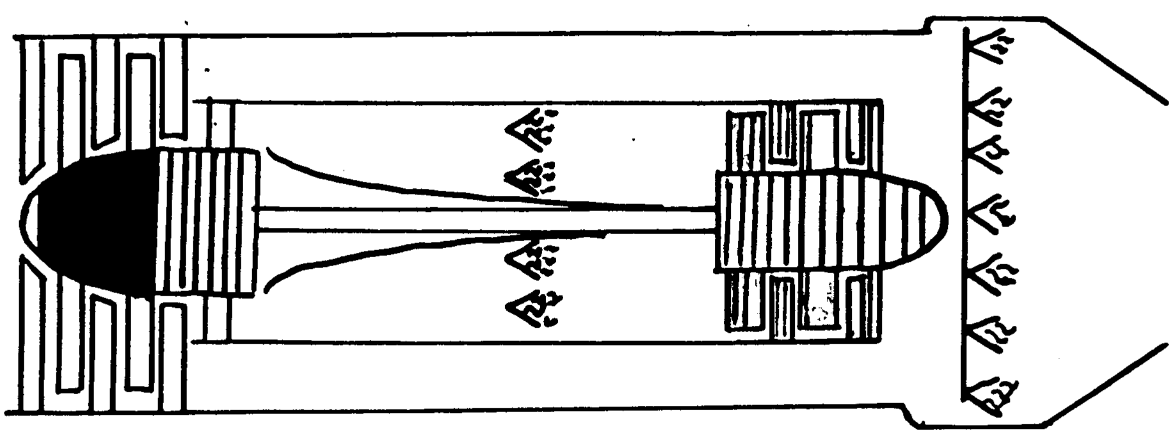


to hold enough LH_2 to give the Leading Edge 250 its 6,500 nautical mile range. This is compared to the 10.2 thousand cubic feet required for liquid methane. Because the density of JP-7 is 48 lbs/ft^3, it would require less volume than liquid methane for the same range. But JP-7 is thermally unstable when its temperature exceeds 550 °F and has a heat sink capability of only 269 Btu/lbm. The 550 °F temperature is too low to be used in a near hypersonic flow propulsion unit since the ram air temperature alone at Mach 3 is 632 °F. JP-7 could not be used as a heat sink for the nozzle, or used in any active cooling process. Liquid methane, on the other hand, has a heat sink capability of about 1,350 Btu/lbm and is thermally stable up to 1,200 °F, and therefore would work adequately in an active cooling process.

7.2 THE PROPULSION UNIT

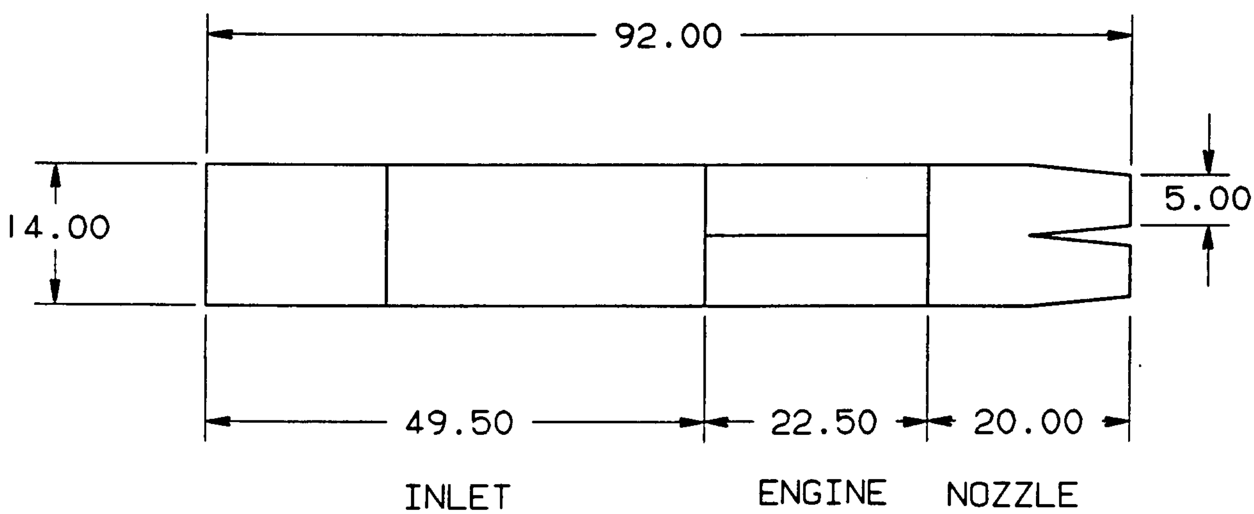
The propulsion plant driving the Leading Edge 250 is a wrap-around turbo ramjet (WTR) shown in Figure 7.2. There are four

FIGURE 7.2 WRAP-AROUND TURBO RAMJET



50K lb static thrust engines, each measuring 7.5 feet in diameter and 22.5 feet long, used on the aircraft. The power plant works like a conventional turbojet while the Leading Edge 250 is at subsonic and low-supersonic speeds. When the flight speed exceeds approximately Mach 3, the turbojet is "turned off" and the surrounding ramjet takes over the task of propelling the aircraft. The length of the WTR with respect to the complete propulsion system is depicted in Figure 7.3.

FIGURE 7.3 PROPULSION SYSTEM



The WTR was chosen over the Air-Turbo Ramjet (ATR) for three reasons. First, the WTR has a better specific fuel consumption (sfc) over the entire flight profile of the aircraft. Figure 7.4 shows that the WTR has a sfc that is 30 percent lower than the ATR at Mach 1 and an altitude of 40,000 feet, and is 31 percent lower at Mach 4 and 70,000 feet. The second reason is rooted in the difference between the ATR and the WTR and how their turbines operate. The WTR's turbine extracts power from the hot, high pressure exhaust gases provided by the burner, like a

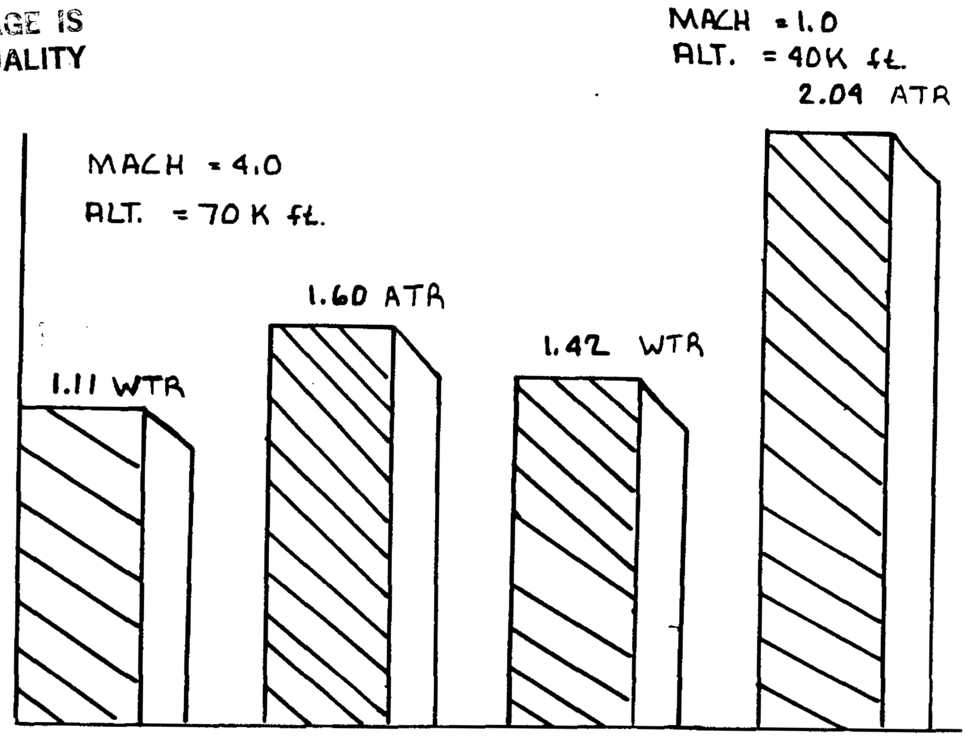


FIGURE 7.4

SPECIFIC

FUEL

CONSUMPTION

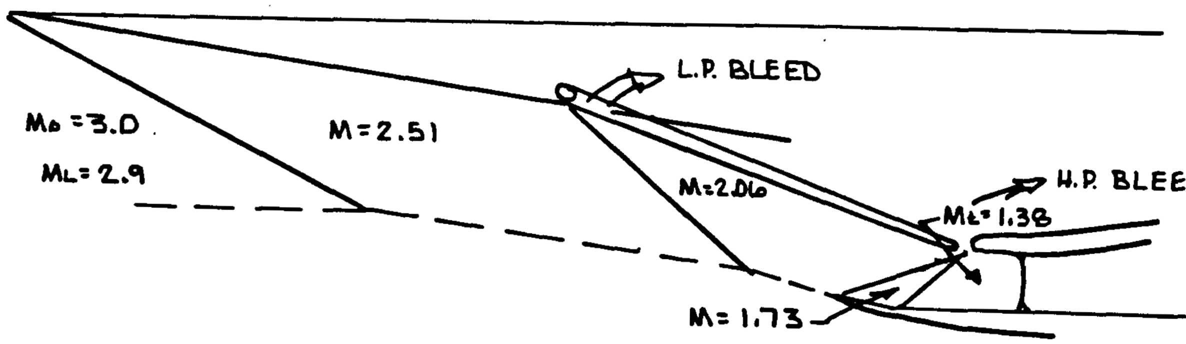
conventional turbojet engine. The ATR's turbine uses hot, high pressure gas generated by a rocket engine. This rocket engine would require liquid oxygen or some other type of oxidizer system to use during its combustion process, which would have to be carried on the aircraft adding complexity and weight to the fuel system. The WTR uses the oxygen in the air. The final reason for choosing the WTR is it involves technology that already exists. The ATR uses new technology, plus, the heat generated by the rocket would mean a complicated cooling process would be required for the turbine blades. This implies that the WTR would have a shorter research and development time. All of these factors translate into a lower engine cost.

7.3 THE INLET

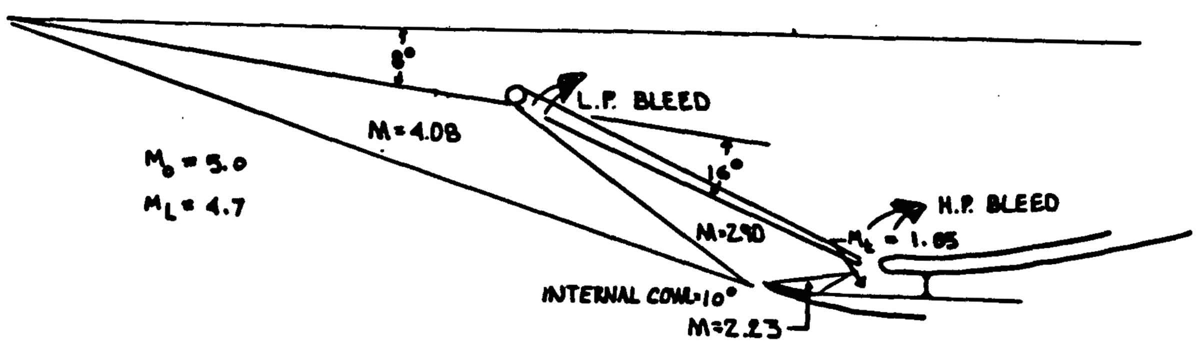
The inlet for the Leading Edge 250 is 49.5 feet long and 14 feet high. It uses four oblique shocks during supersonic flight to diffuse the freestream airflow before going through a normal

shock at the inlet throat. The inlet is designed to provide up to 41 slugs/sec of air to the engines. There are two inlets, one on each side of the fuselage, each feeding two engines. They provide both low pressure bleed air, extracted after the second shock, and high pressure air, extracted after the forth shock. The total pressure recovery for the inlet at Mach 3 operation is 0.90, while at Mach 5 it is 0.55. Schematics of the inlet operation at Mach 3 and 5 are shown in Figure 7.5.

FIGURE 7.5 INLET OPERATION



MACH 3.0 OPERATION $\pi_D \approx 0.90$



MACH 5.0 OPERATION $\pi_D \approx 0.90$

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7.4 THE NOZZLE

There are four nozzles on the Leading Edge 250 HSCT. Each is 11.4 feet long with a throat diameter of 3.96 feet and a maximum exit diameter of 10.0 feet. The nozzle has two operational modes (see Figure 7.6). In the subsonic flight regime, the nozzle is purely a convergent nozzle. The throat has a diameter of 3.96 feet and bleed air flows into the secondary nozzle at this point. The second operational mode is in the supersonic flight regime. Here, the throat diameter becomes 6.14 feet after the primary nozzle opens to mate with the secondary nozzle, allowing an expansion of the exhaust gases.

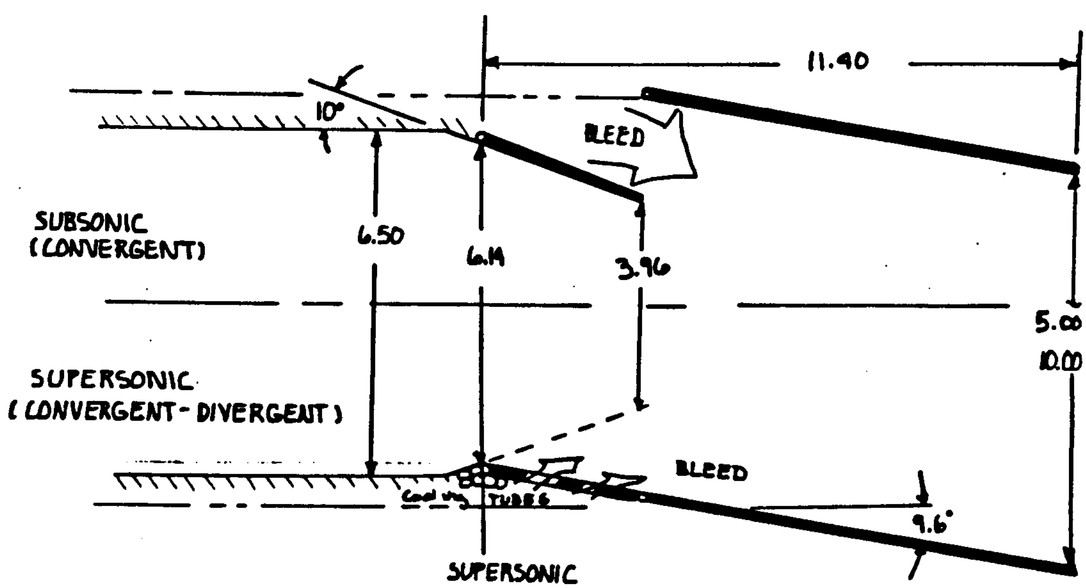

FIGURE 7.6 NOZZLE DESIGN

The throat of the nozzle is cooled using the liquid methane fuel of the Leading Edge 250. This serves the added function of preheating the fuel before entering the engine. This should increase the burner efficiency.

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8.0 PERFORMANCE

The only performance requirements specified by the RFP are as follows: a critical field length of 11,500 feet, a cruise Mach number of 3 to 6, and a cruise range of 6,500 nautical miles with a passenger load of 250 persons. The performance of the Leading Edge 250 was analyzed using methods outlined in Reference 3. This analysis was limited to takeoff, climb, cruise, descent and landing. The results showed that the Leading Edge 250 meets the requirements of the RFP.

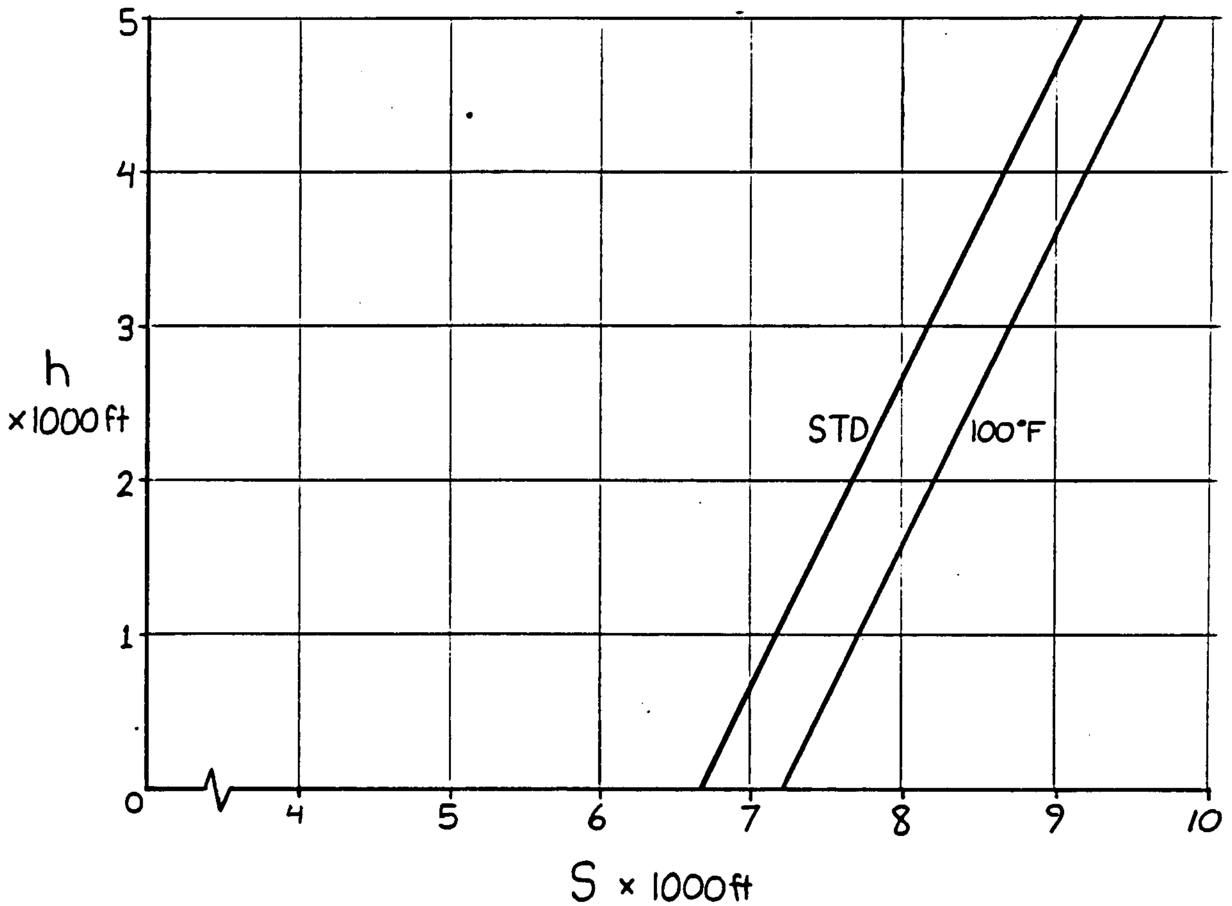
8.1 TAKEOFF PERFORMANCE

The takeoff distances for the Leading Edge 250 were calculated at altitudes ranging from sea level to 5,000 feet for standard day conditions, and for a 100 °F day. Takeoff velocities ranged from 188 knots at sea level-standard to 222 knots at 5,000 feet on the 100 °F day. The ground roll distance for the aircraft was determined using lift, drag and thrust terms evaluated at a velocity of $0.7V_{TO}$. The average ground resistance coefficient, mu, was set equal to 0.05 for a concrete runway.

The rotation distance was assumed to be the distance covered by the aircraft during a three second rotation maneuver. The velocity of the Leading Edge 250 at this point was equal to the takeoff velocity. Although the FAR Part 25 does not require the aircraft to clear a 50 foot barrier on takeoff, this constraint was included in the analysis as a safety factor. The variation in total takeoff distances for the range of analysis conditions

is presented in Figure 8.1. This plot shows that the Leading

FIGURE 8.1 TAKEOFF DISTANCE



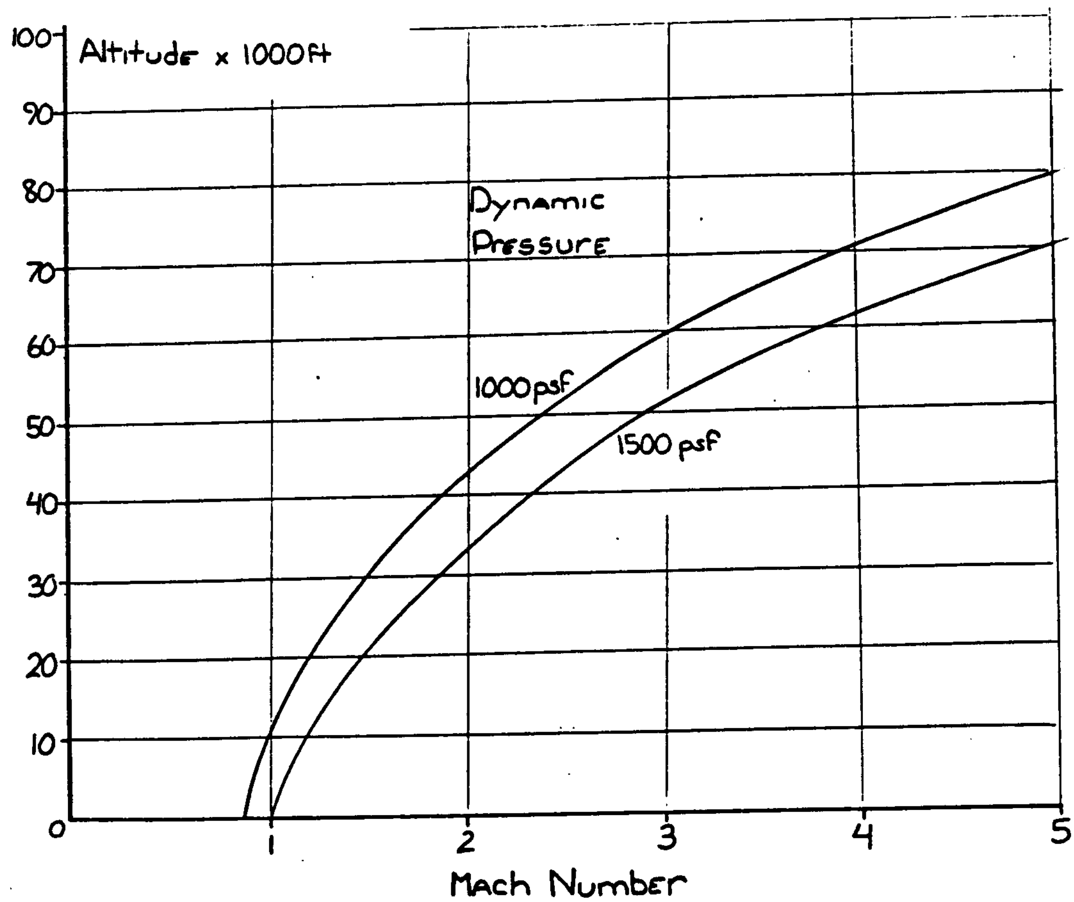
Edge 250 meets the RFP takeoff requirement for all cases considered. At the worst case for a 100 °F day at 5,000 feet, a margin of 1,800 feet exists between the required and available field length.

8.2 CLIMB/CRUISE PERFORMANCE

The climb schedule was governed by the aircraft's dynamic pressure limit and excess power at any particular flight condition. Contemporary supersonic aircraft are typically designed to withstand a maximum dynamic pressure of 1,800

lbf/ft². This was assumed to be the case for the Leading Edge 250, but for analysis purposes the upper limit was set at 1,500 lbf/ft² to provide a margin of safety. The dynamic pressure, as a function of Mach number and altitude, is plotted in Figure 8.2.

FIGURE 8.2 DYNAMIC PRESSURE

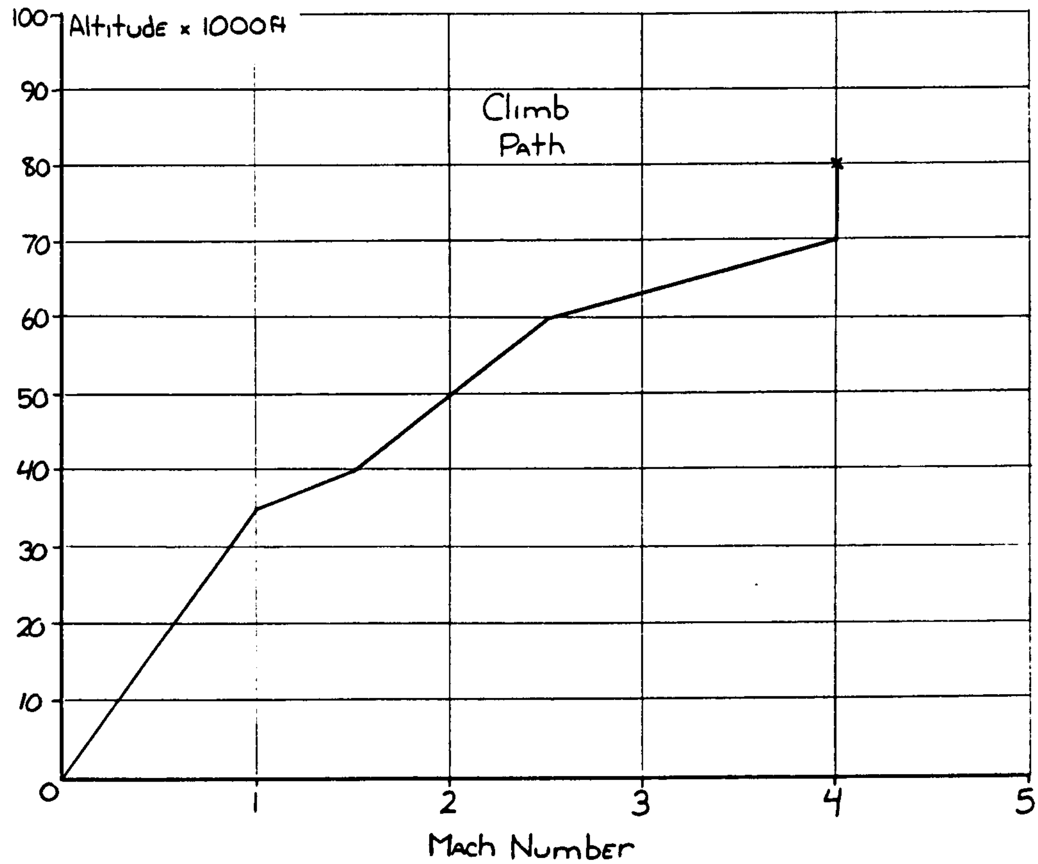


The minimum dynamic pressure limit at takeoff conditions was 84 lbf/ft², based on a lift coefficient of 2.0. For ease of computation, the lower limit was set at 100 lbf/ft² for all flight conditions.

The climb path was determined by the combinations of Mach numbers and altitudes below the maximum pressure limit which yielded the highest specific excess power. The path is shown in

Figure 8.3. It can be seen that the aircraft attains the design

FIGURE 8.3 **CLIMB PATH**



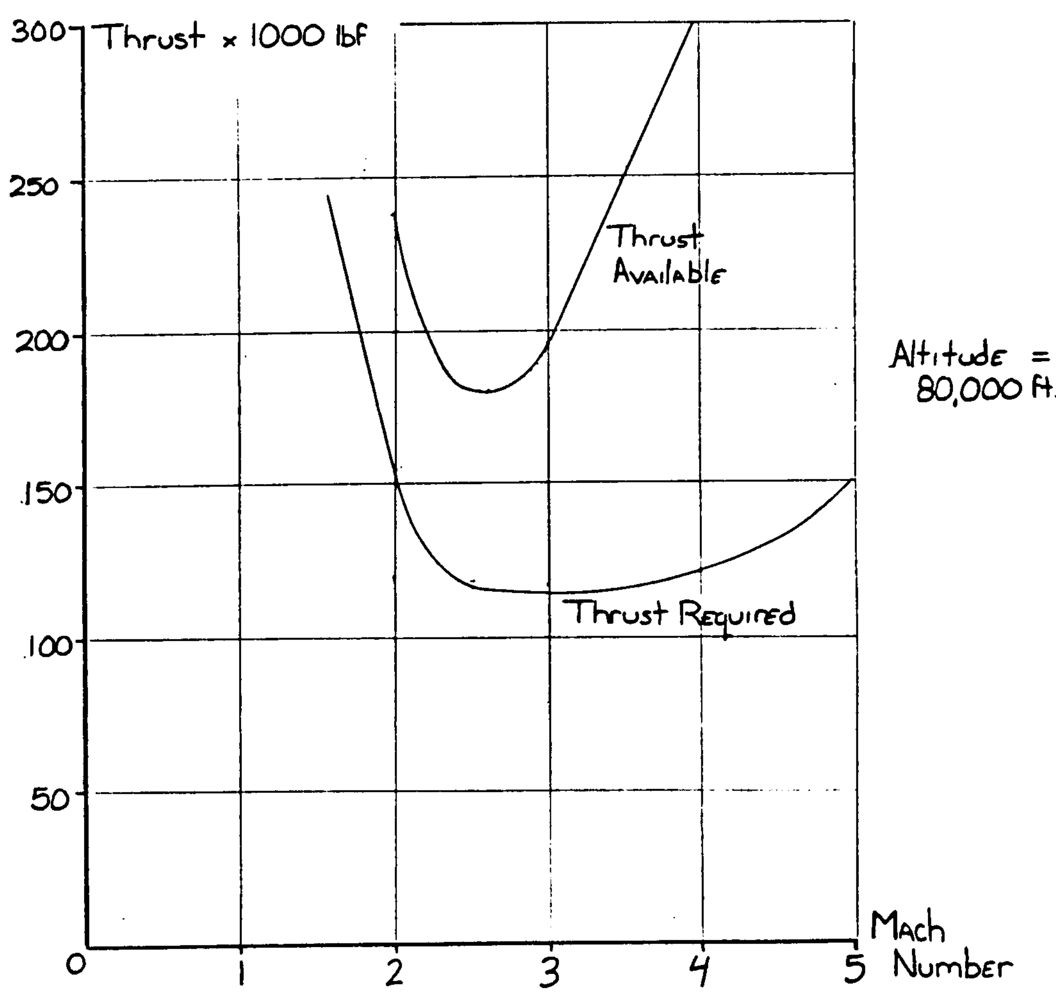
cruise Mach number of four before climbing to the 80,000 ft. cruise altitude.

The Leading Edge 250 uses 52,082 lbs of fuel during climb and acceleration. The horizontal distance covered during this phase is 800 nautical miles. The maximum climb angle was restricted to three degrees and the acceleration to 0.1 g for the comfort of the passengers.

The required cruise thrust was determined for an unaccelerated flight condition where thrust equals drag. At Mach 4 and 80,000 feet, the Leading Edge 250 needs 120,000 lbf of thrust, or 30,000 lbf from each of the four engines. From the

engine performance analysis, the available thrust at this point was 305,000 lbf total from four engines, or 2.54 times the required level. This would enable the engines to be throttled back during cruise, resulting in lower fuel consumption. The engines cannot be sized down to match the cruise condition without adversely affecting the subsonic flight performance, most notably the takeoff distance. The required thrust for a range of Mach numbers at 80,000 feet is plotted in Figure 8.4, together with the available thrust.

FIGURE 8.4 **THRUST REQUIRED**



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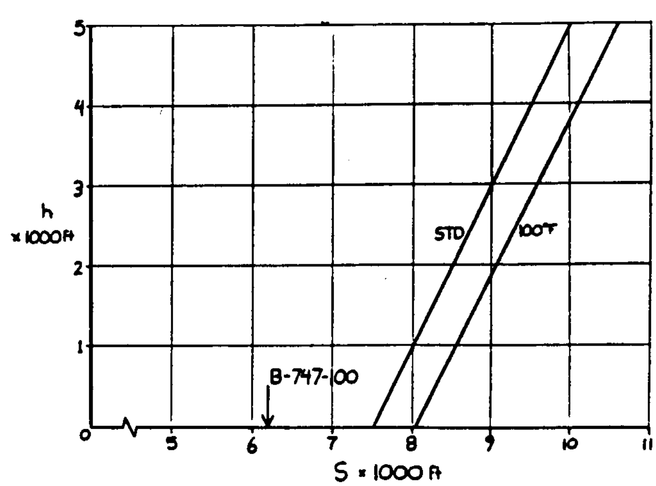
8.3 LANDING PERFORMANCE

The landing performance analysis was performed for altitudes from sea level to 5,000 feet at standard day and 100 °F conditions. In the case of landing, FAR Part 25 requires that the total landing distance incudes an approach over a 50 foot object. The weight used in the calculations corresponds to an aircraft with a 50% fuel load. The stall velocities at this weight range from 142 knots to 167 knots. The approach velocity over the obstacle is 1.3 times the stall velocity, and the touchdown velocity is equal to 1.15 times the stall speed.

A free roll of three seconds before the application of the brakes was assumed. The distance covered during this time was evaluated at the touchdown velocity. For braking distance calculations, the wheel brakes were the only retarding devices considered. Use of thrust reversers would reduce the landing run, but at the cost of increased weight. The total landing distances are plotted in Figure 8.5 as functions of altitude and temperature. The distance at sea level standard was 7,500 feet.

FIGURE 8.5

LANDING DISTANCE



The distance on a 100 °F day at 5,000 feet was 10,600 feet, 900 feet shorter than the RFP requirement. Because this margin is equivalent to less than four aircraft lengths, the effects of adverse conditions could be critical. The sea level landing distance for a Boeing 747-100B is also indicated in Figure 8.5 for comparison.

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9.0 NOISE

The Leading Edge 250 HSCT is a Mach 4+ transport which cannot avoid producing a strong shock wave at cruise conditions. However, because it will fly international routes, most of its flight time will be spent over oceans. But when flying over populated areas is a necessity, the Leading Edge 250 has the unique advantage of being able to decrease its Mach number, rotate its wing accordingly, and continue cruising efficiently. As stated previously, the sonic boom produced by an oblique wing is less than that of conventional supersonic designs due to the fact that the lift and volume of the wing is distributed over a greater longitudinal distance (Ref. 1 & 2). The aircraft was found to be able to meet the RFP requirement of not producing overpressures above one pound per square foot.

Because the Leading Edge 250 requires less takeoff distance when its wing is unswept, and has a higher climb rate, it possesses a smaller noise footprint than many modern transports.

Internal cabin noise produced by the engines should not be a problem due to the fact that the they are located almost 20 feet aft of the passenger cabin. With the use of sound insulation, noise produced by the engines could be negated almost completely.

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10.0 STRUCTURES

The purpose of this chapter is to discuss the structural design philosophy used in the Leading Edge 250. This discussion will include:

Thermostructural analysis

Structural geometry

Materials used

Location of structural components and their geometries

Equipment included in the structure.

In general, the entire structure of Leading Edge 250 is designed around the heat sink concept. It is designed to withstand the aerodynamic heat loads without having to resort to active cooling. The purpose of this is to:

Minimize the complexity of structure

Maximize the safety

Avoid circulating the liquid methane (as the cooling agent) into the main structure.

Titanium will be used for the most of the primary structure (about 75%). This is necessary due to thermal, fatigue, and corrosion reasons. All the spars and ribs used in the structure are made of corrugated steel. This is done because corrugated spar constructions have been proven to be self-stabilizing.

10.1 THERMAL ANALYSIS

A computer program was generated to calculate the maximum temperatures expected for three cruise conditions; cruise Mach

numbers of 3, 4, and 5. The model had 12 elements. An incremental iteration method was used to calculate the temperature-time history at the centroid of each element. The assumptions used in these analysis were:

The wing has no sweep

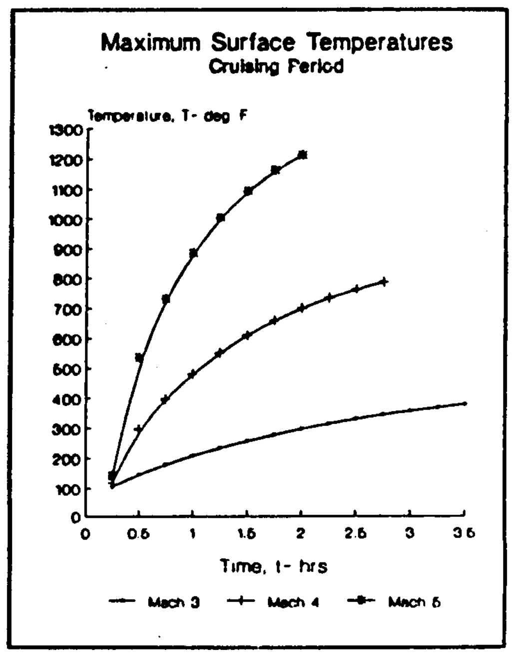
The flow is turbulent

The temperature of space is at absolute zero and the temperature of earth is at 70 °F

No spanwise conduction.

The results of this analysis are presented in Figure 10.1. Also obtained from the program were the time histories of heat flux distributions on the wing. These heat fluxes (Figures 10.2, .3, .4 and .5) were later used to perform the thermostructural analysis of the wing, utilizing NASTRAN. It was determined from these results that at Mach 4 cruise, the stagnation temperature will be approximately 780 °F.

FIGURE 10.1



10.2 NASTRAN 3-D THERMOSTRUCTURAL ANALYSIS

A NASTRAN model was generated to perform a 3-D, thermostructural analysis. The model is shown in Figure 10.6. The method used for the thermostructural analysis is as follows:

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FIGURE 10.2 c = 12 ft

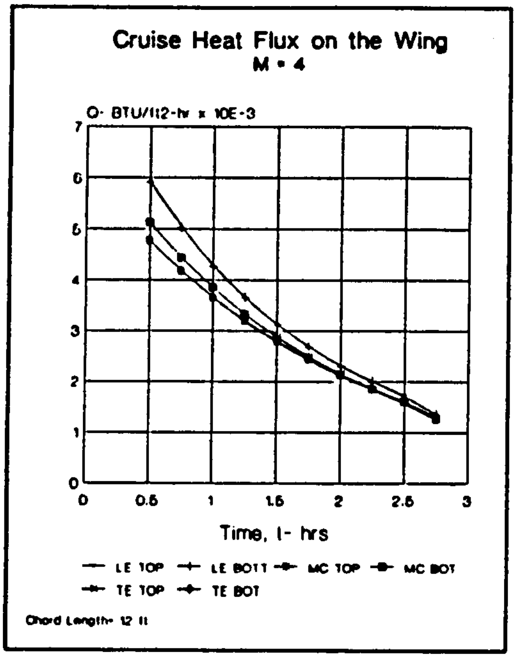


FIGURE 10.3 c = 18 ft

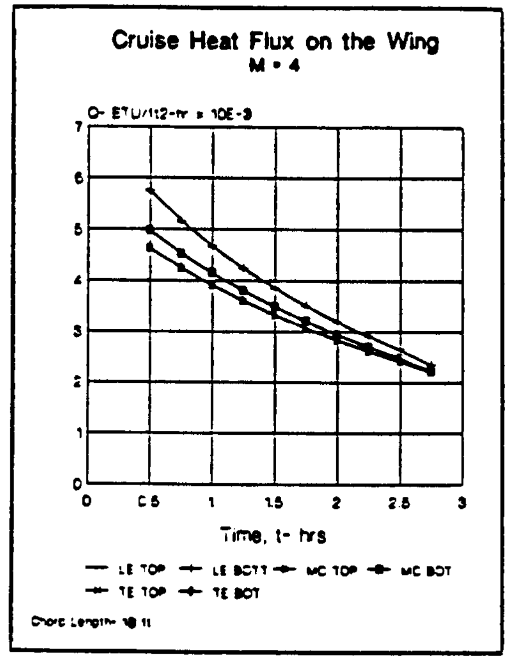


FIGURE 10.4 c = 23 ft

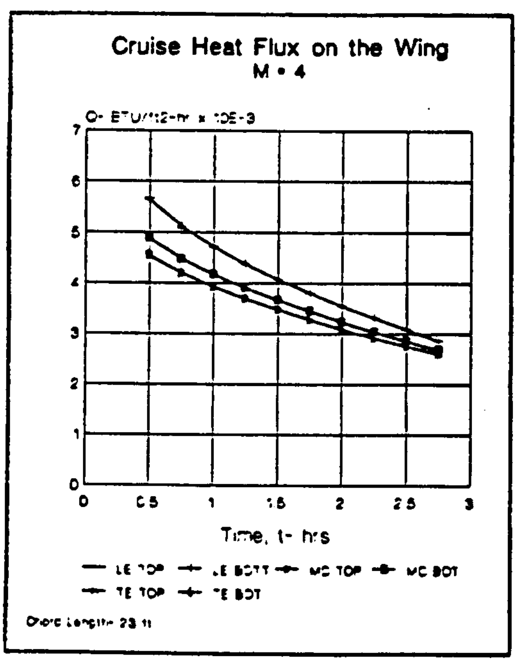
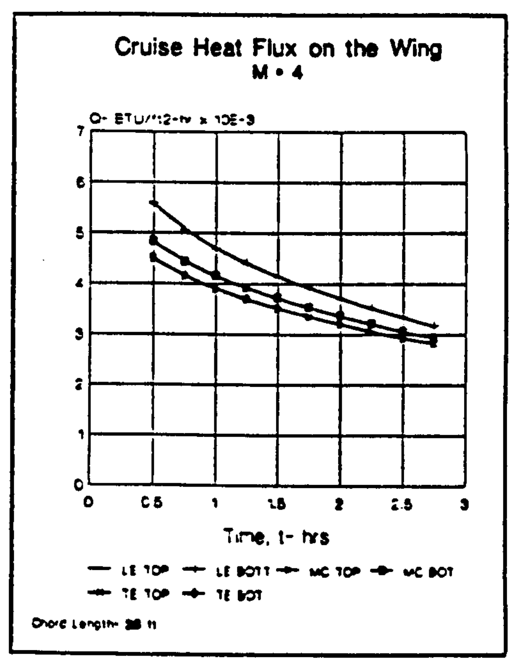


FIGURE 10.5 c = 28 ft



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1. The heat flux curve (obtained from 2-D analysis) was approximated at three time intervals.
2. These heat flux values were inputed into the NASTRAN thermal file and the file was run for the specified time interval.
3. Outputed were the new temperatures at all the grid points of the model.
4. These new temperatures were copied back into the thermal file and were chosen as the initial conditions for the next time step. Also, the heat flux values were changed (to approximate the heat flux curve for this time increment).
5. The procedure was repeated until the final temperatures at the end of the cruise were obtained. Figure 10.7 shows the comparison of maximum temperatures obtained by both analysis.
6. The final temperatures were inputed into the structural file and were specified as thermal loads (referring to initial material temperature at 530 °R).

   Requested were the direct stresses at the grid points. Some of the results are presented in Figure 10.8.

It should be noted, looking at Figure 10.7, that the assumption that the spanwise heat conduction is negligible was valid.

FIGURE 10.6 NASTRAN 3-D THERMOSTRUCTURAL MODEL

not to scale

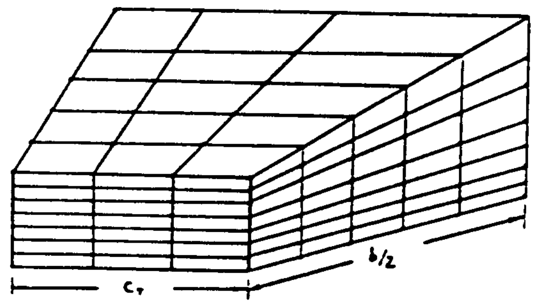


FIGURE 10.7

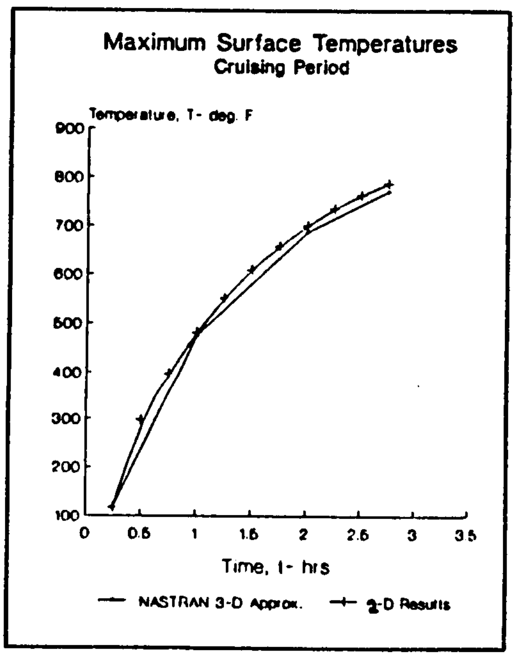
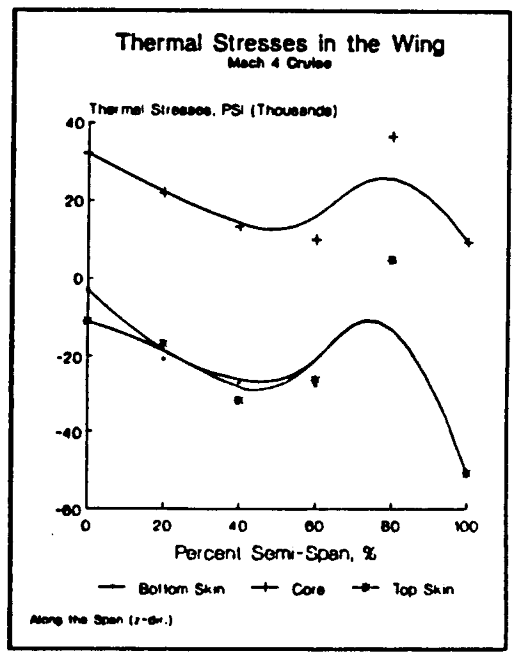


FIGURE 10.8



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10.3 MATERIAL SELECTION

The selection of materials used in the primary structure was based mainly on strength to weight and weight to temperature limit comparisons. Weight to cost comparison for most of the materials was not performed, because the costs were not available. The comparison charts are presented in Figures 10.9 and 10.10. Based on these figures, it was determined that the titanium (6Al-6V) and steel (D6AC) alloys were the best candidates for the project. The temperature limits of these materials are 900 °F and 1,200 °F, respectively. The endurance limits of these materials are approximately 50,000 psi and 69,000 psi, respectively.

FIGURE 10.9

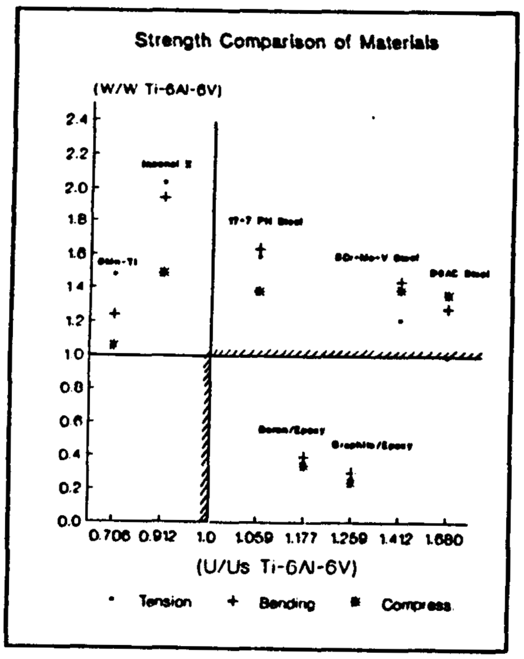
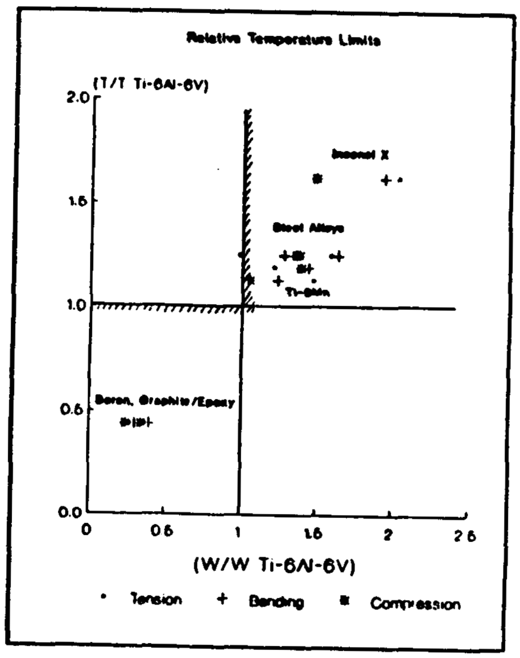


FIGURE 10.10



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10.4 SHEAR, BENDING, and TORSION ANALYSIS

Shear, bending, and torsion analysis (Reference 6 & 7) were performed on the wing for the takeoff conditions, because this is when the maximum bending moments assure on Leading Edge 250. The results are presented in Figures 10.11-10.13. The assumption made in all this analysis is that the wing load is distributed uniformly.

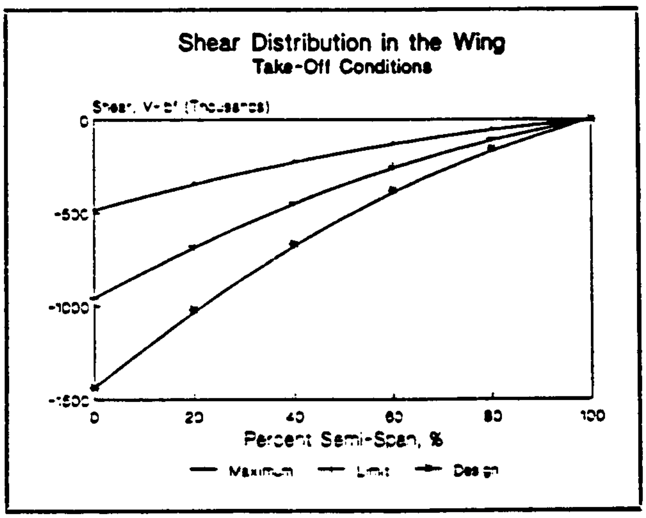
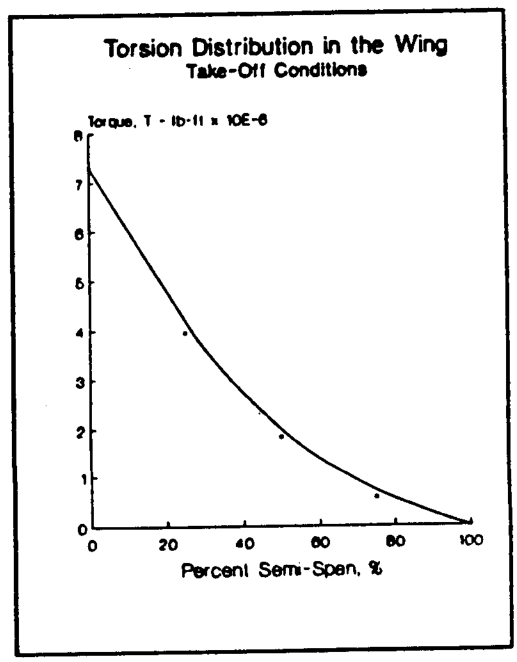


FIGURE 10.11

FIGURE 10.12



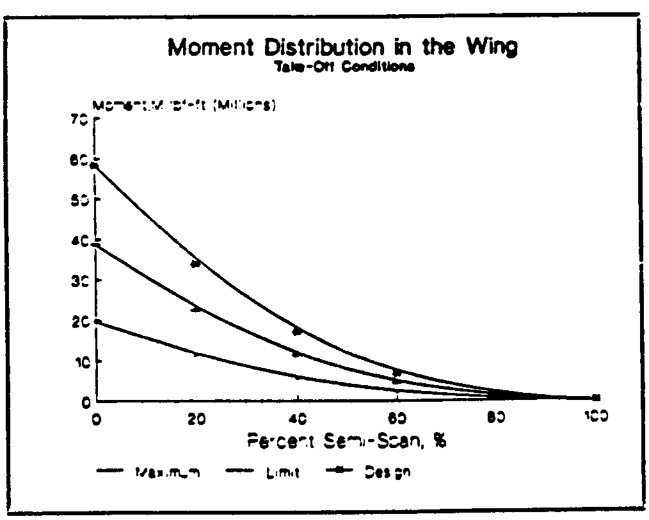


FIGURE 10.13

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10.5 WING STRUCTURE

The items which must be carried in the wing include:

Wing structure with provisions to maintain the airfoil geometry

Flap drive systems

Heat sink systems.

The wing structure of the Leading Edge 250 is presented in Figure 10.14. The wing is constructed of titanium skin and corrugated steel spars and ribs. The wing has five corrugated spars. The three main spars (I-cross section) are located at 25%, 40% and 55% wing chord. Their main purpose is:

To take most of the large bending moments developed during take-off

To take out large torsion developed in the wing

To prevent the skin from buckling.

The main spars extend from the root of the wing to 60% of semi-span. They are not used beyond this point for the following reasons:

Bending moments are small and can be taken by the remaining two spars

Torsion also is small and can be taken out by the other two spars

To minimize the weight.

The other two spars (C-cross section) are located at 10% and 70% wing chord. Their purpose:

To take the bending moments

To take out the torsion

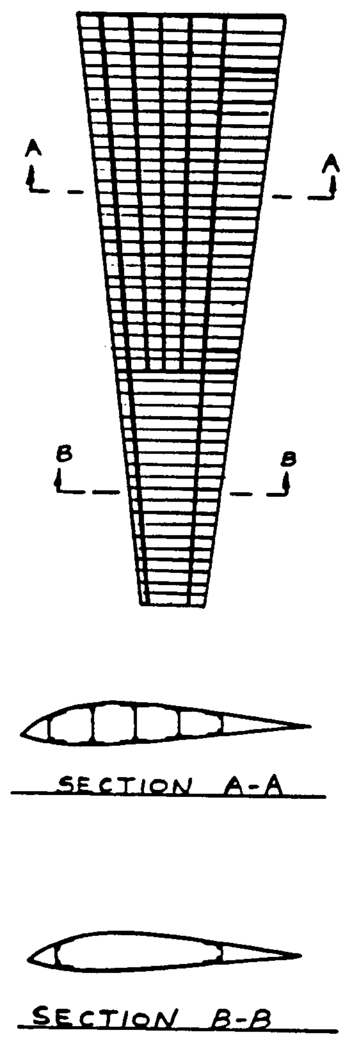
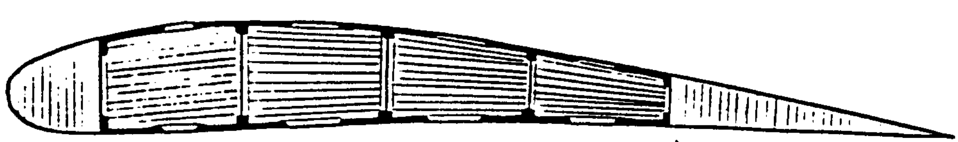


FIGURE 10.14

WING STRUCTURE

FIGURE 10.15 WING AIRFOIL CLOSE-UP



To provide attachment points for the flaps and leading edge wing ribs.

Using steel instead of titanium for the spars presents few advantages:

Low cost/high strength

Better fatigue properties

Larger expansion rate (compared to titanium skin), which for a given temperature difference will cause the stresses to be relieved.

To withstand the design loads (at the wing root bulkheads), the I-section spars have a web thickness of 0.76 inches flange thickness and length of 4 inches and 36 inches respectively. The two C-section spars have a web thickness of 0.76 inches and flange thickness and length of 3 inches and 25 inches respectively. The spars taper from root to tip to minimize the weight.

Rib spacing is shown in Figure 10.14. The critical function of the ribs in the aircraft is to maintain the airfoil geometry and they are placed 24 inches (2 ft) apart to achieve this. They are constructed of six pieces from 0-60% semi-span and in three pieces from 60-100% semi-span. Again, D6AC steel is used to minimize cost.

The skin of Leading Edge 250 is made of solid sheets of titanium alloy 6Al-6V. A sandwich structure for the skin did not present any weight savings in this case and therefore was avoided. Titanium was chosen because of the following reasons:

High temperature limit

Excellent fatigue properties

Good corrosion-resistant properties

Relatively light.

The heat sink structure of aircraft consists of layers of honeycomb (square cell core) sandwich panels (Figure 10.15). The panels use low density, high temperature material (steel). The low density is achieved by controlling the size of the core cells and the thickness of the foil. The honeycomb core used in the Leading Edge 250 has a density of 2.3 lb/ft^3 (only 0.5% of that of steel). The cell size used is (12 in) and the thickness of the foil is 0.03 in. Since these honeycomb structures are not the load carrying components in this case, the facings are made of very thin foils. This concept has several advantages:

The heat sink (honeycomb panels) structures can be manufactured separately based on the specifications

Once they are manufactured, they can be assembled onto the aircraft as whole components, therefore simplifying the assembly process

It eliminates the need for active cooling, which simplifies the structure.

It should be noted that sandwich panels are not as good as solid panels in conducting heat (acting as heat sinks), but they present considerable weight savings.

10.6 FUSELAGE STRUCTURE

Items which are carried in the fuselage are:

Cabin with controls, instruments and seating for the

passengers

Flight controls, instruments and sensors

Fuel tanks

Baggage compartment

Electrical/Hydraulic systems

Environmental control system

Attachment points for the wing "torque box" and the landing gears.

A section of the Leading Edge 250 fuselage structure is shown in Figure 10.16. The primary fuselage structure is made of honeycomb (titanium-steel) shell, longerons, and frames spaced at approximately 24 in apart.

The shell carries the shear loads, and part of the fuel and cabin pressure loads. Longerons carry the bending loads and most of the fuel and cabin pressure loads. The sandwich panels are generally one inch thick with face sheet of 0.06 in.

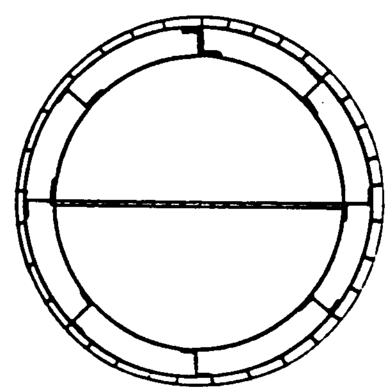


FIGURE 10.16 FUSELAGE STRUCTURE

To prevent the inner walls of the passenger cabin from heating, the walls (and the structure) will be cooled by circulating the conditioned air from the cabin through special ducts between the inner and outer sandwich panels.

To protect the fuel tanks from heating, the fuel will be circulated around the fuel tanks before going to the engine,

thus, keeping the fuel tank at a constant temperature.

10.7 VERTICAL TAIL STRUCTURE

Items which will be carried in the vertical tail are:

Spar and rib structures, including support structure for the horizontal tail

Controls and hinges

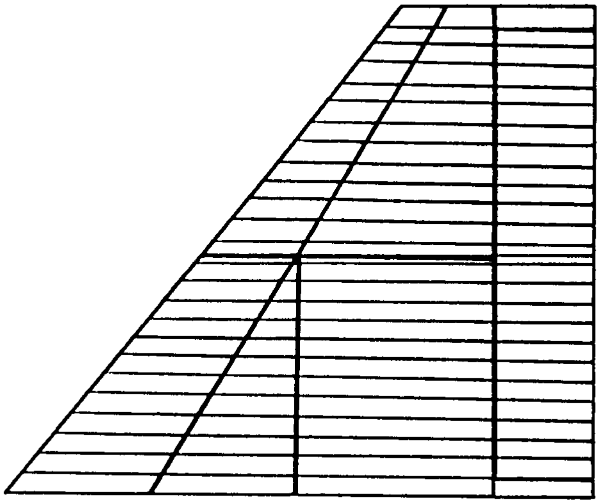
Electrical wiring for navigation and lights.

The vertical tail structure of the Leading Edge 250 is shown in Figure 10.17. The spars and ribs are made of corrugated D6AC steel alloy. The purpose of the front and rear spars (at 25% and 83% tail root cord) is to take the bending moments and torsion, and to provide attachment points to the leading edge ribs and the rudder. The purpose of the horizontal spar is to provide a rigid attachment point for the horizontal tail structure. The vertical spar at 50% root chord is a support column for the front and the horizontal spars.

The rib spacing in the vertical tail is at every 12 inches. The ribs, again, are made of D6AC corrugated steel alloy. The heat sink structure is similar to the wing structure.

10.8 HORIZONTAL TAIL

The horizontal tail is very similar to the wing structure. There are two spars, located at 25% and 70% wing chord. The rear spar provides the attachment points for the elevators. The materials and the heat sink structures are identical to that of the wing structure. Figure 10.18 shows the horizontal wing.



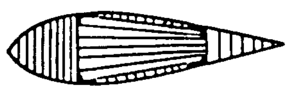
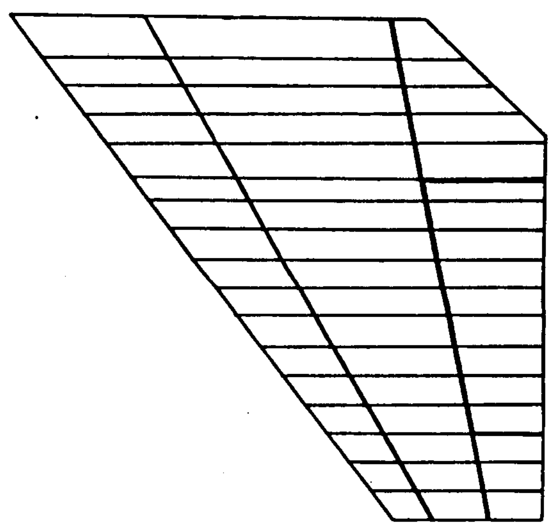


FIGURE 10.17 VERTICAL TAIL STRUCTURE



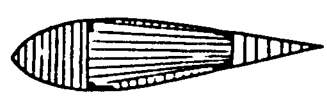


FIGURE 10.18 HORIZONTAL TAIL STUCTURE

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10.9 LANDING GEAR STRUCTURES

The landing gear was sized for the maximum takeoff weight of the Leading Edge 250 (Reference 8). Dual twin configuration was used for the nose gear and twin tandem for the main gear (Figure 10.19). The tires were assumed to have as ax/g of 0.45 (anti-skid brakes). Allowing for a 25% airplane weight growth, the nose gear would be required to carry a load of 217,103 lbf or a load of 54,276 lbf per tire.

For the main landing gear, allowing for a 25% weight growth, the load required to carry is 202,131 lbf. For each tire in the main landing gear the load is 50,533 lbf. The maximum tire velocities calculated were 283 ft/sec (193 mph).

A Goodrich 52.0x20.5, 26 ply tire will carry a maximum load of 55,000 lbs, has a pressure requirement of 165 psi and a maximum speed of 235 mph. Thus, it is used for the nose and the main landing gears.

The length of the struts were calculated assuming that the entire touch down energy is absorbed by the main landing gear. The landing gear load factor was assumed to be 1.75 (FAR 25: Ng=1.5-2.0) and shock absorber efficiency used was 0.8 (0.75-0.85 for the liquid springs).

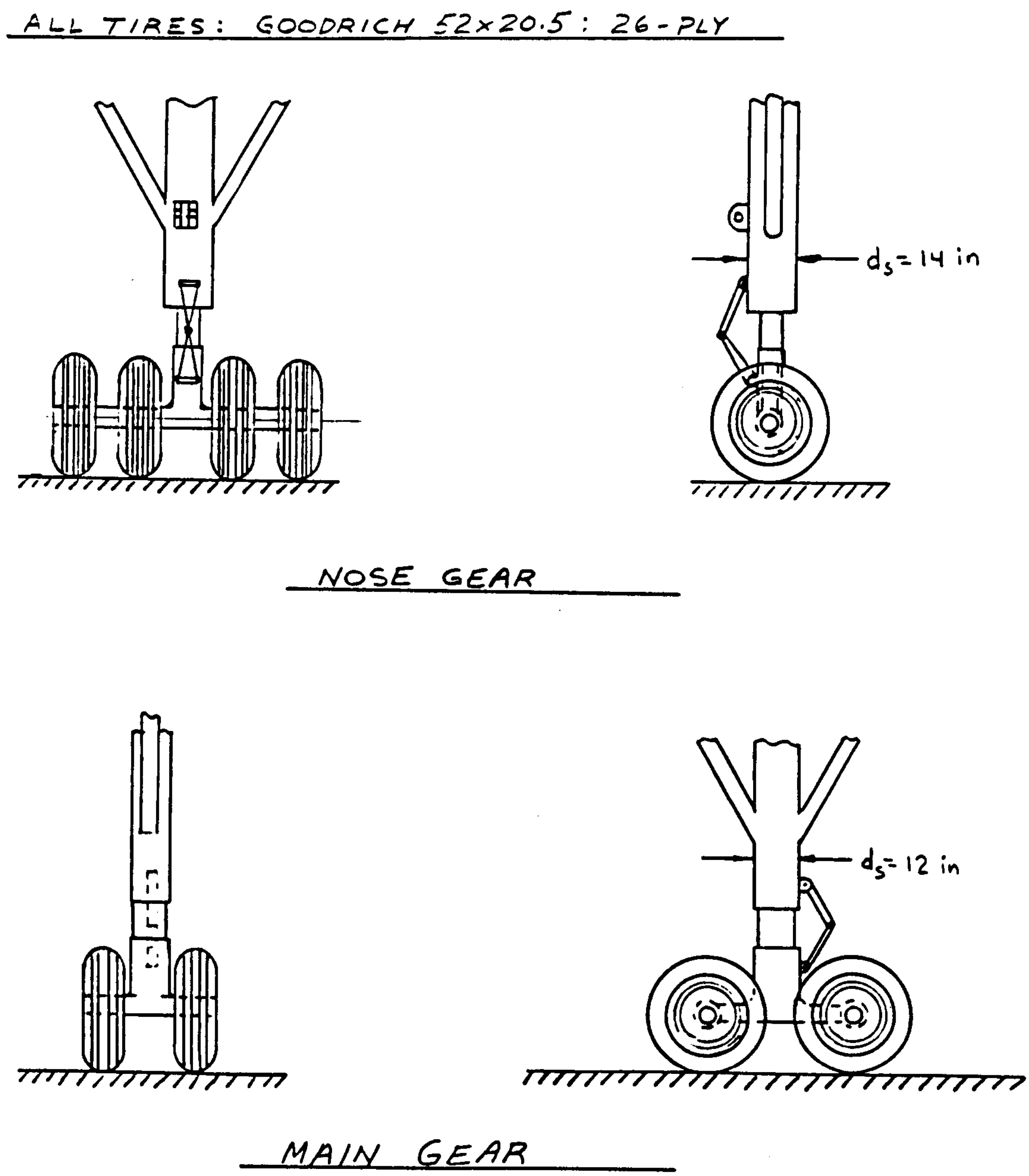
For the main landing gear, the shock absorber lengths are 9 in (0.75 ft) and the diameters are 12.2 in (1.02 ft). The nose landing gear, the shock absorber length is 29 in (2.42 ft) and the diameter is 14.2 in (1.18 ft).

All the shock absorbers used are liquid spring type. This type of spring was chosen considering the magnitude of loads and

its good damping abilities. The fluid used in these springs is Dow-Corning F-4029.

The landing gear was placed to meet the longitudinal and lateral tip-over criteria. The gear location was shown in Figure 3.1.

FIGURE 10.19 LANDING GEAR STRUCTURE



11.0 CABIN LAYOUT

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The cabin dimensions, including passenger seats, lavatories, galleys, cockpit, and cargo bay, are discussed here. Figure 11.1 provides the sideview of the Leading Edge 250 inboard profile. It also shows two topview sections near an exit and the rear bulkhead. In Section A, first class and second class seats are visible, along with the arrangement of the lavatories and a galley near a normal and emergency exit. Section B shows the rear of the cabin with second class seating, four lavatories, and two galleys. Also shown are two fold down seats used by flight attendants. A cross sectional view of the first class seating section showing overhead carry-on baggage storage is provided.

The Leading Edge 250 has 34 first class seats arranged in five rows of six seats at 38 inch pitch. One additional row at the front of the first class section contains the last four seats, the center two seats removed for easy access into the cockpit. The next section back contains second class seating, with 112 seats arranged in 16 rows of seven seats each at 34 inch pitch. The general arrangement of the second class rows can be viewed in both Section A and B topviews. The next second class section also contains 112 seats arranged in 16 rows identical to the forward second class section. The total number of seats is then 258. The extra 8 seats are used by the flight attendants.

The size of the seats were determined using Reference 9. The first class seats are 20 inches wide with two 2 inch armrests. The second class seats are 17 inches wide, also with

two 2 inch armrests.

There are a total of 9 lavatories in the aircraft. One is located next to the forward exit, behind the cockpit. Across from it is a wardrobe. Two are located forward of the second exit from the front of the aircraft, as shown in the Section A topview. And two more lavatories are located in an identical manner in front of the third exit. The remaining four lavatories are located to the rear of the aircraft as shown it the Section B topview. All lavatories are 3 feet by 6 feet in dimension. They were sized by examining lavatory dimensions in existing aircraft.

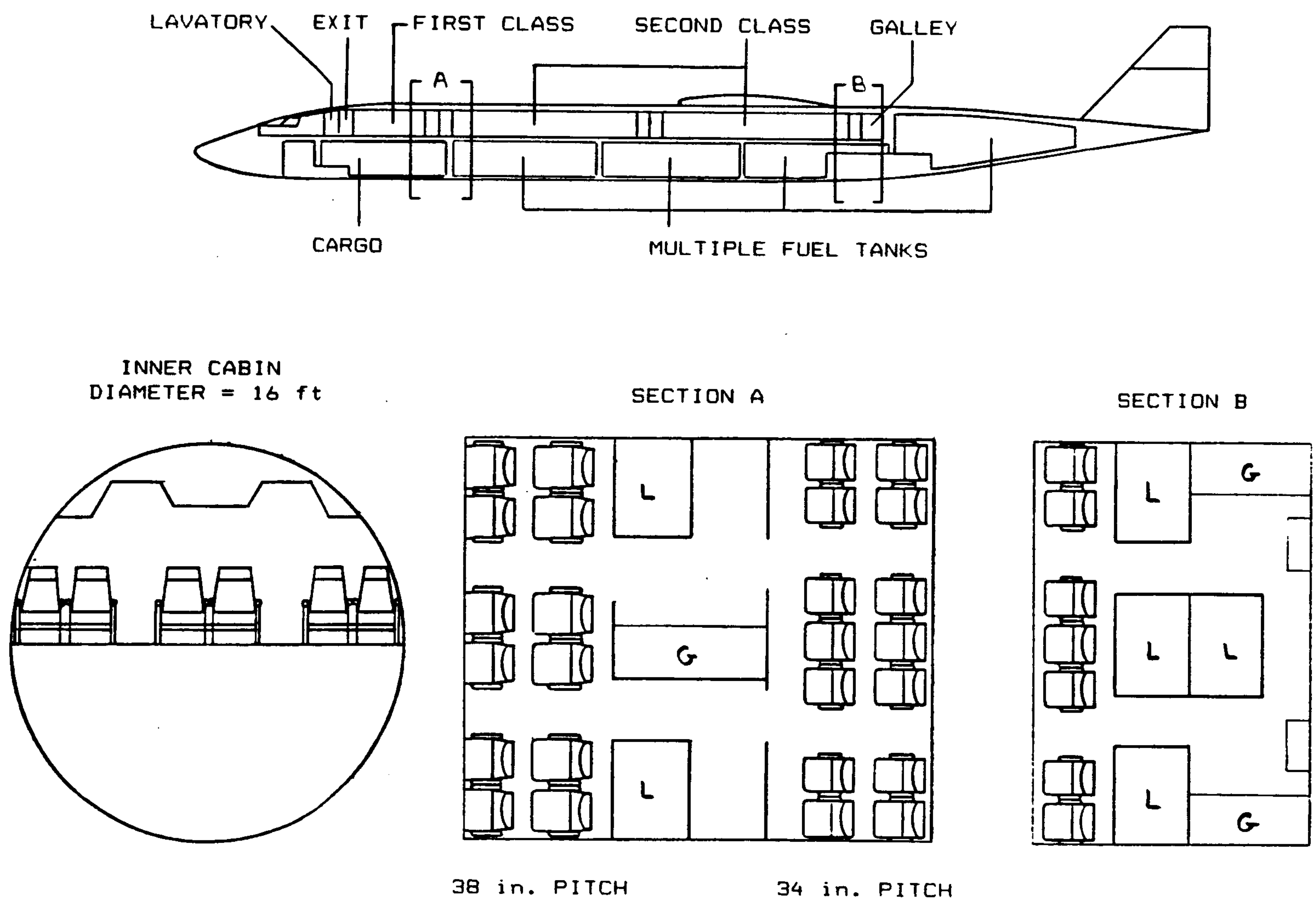
A total of 4 galleys are present in the aircraft. Two are located at the rear of the aircraft, as shown in Section B topview. And the remaining galleys are located by the second and third exits from the nose, and are placed as shown in the Section A topview.

The total cabin length is 136 feet. The cockpit is 17 feet, including all avionics and controls forward of the pilots' seats.

The cargo hold was sized by assuming a baggage volume of 10 cubic feet per person. This gives a volume of 2,600 cu.ft., though the total cargo hold volume is 3,900 cu.ft. providing an extra 1,300 cu.ft. of space. It is located, as shown in the sideview of the aircraft, below the first class seating section.

The Leading Edge 250 has a total of 6 exits located across from each other in pairs along the length of the aircraft. These exits can be seen in Figure 3.1. Three of the doors, located on the aircraft's left side, are used to load and unload passengers. The right side doors are available as emergency exits.

FIGURE 11.1 **LE 250 INBOARD PROFILE (SIDEVIEW)**



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12.0 AIRCRAFT SYSTEMS

This section describes briefly the fuel system and hydraulic system designed for the Leading Edge 250 HSCT. The layout of each is presented also.

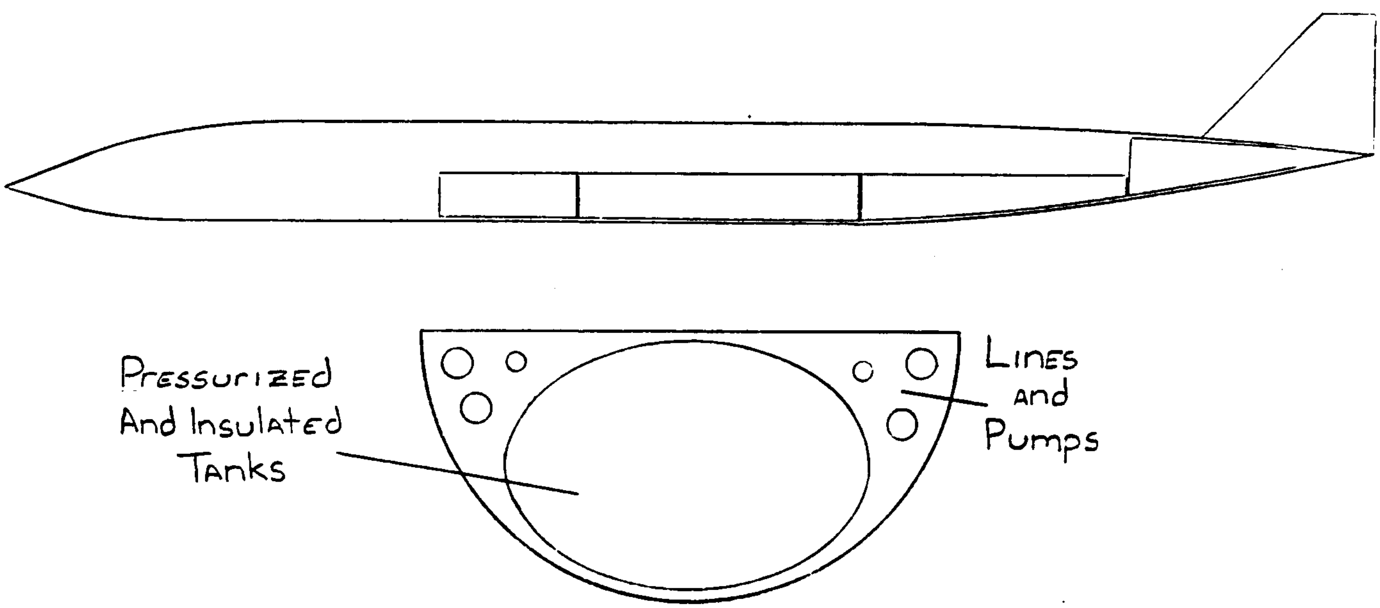
12.1 FUEL SYSTEM

The fuel system layout was initially based on that of the Concorde and also the Boeing 767 as illustrated in Reference 10. However, the use of liquid methane as fuel precluded the use of several of the features found in more conventional aircraft. Integral tanks were eliminated because cryogenic fluids must be stored in insulated pressure vessels. Such tanks require a spherical or cylindrical shape, and their bulk can not be accommodated in the six percent thickness wing used by the Leading Edge 250. The wing is also a high heat flow region incompatible with liquid methane's low storage temperatures. The only other possible tank location was in the fuselage.

In order to prevent large shifts in the center of gravity as the fuel is drained from the tanks, they had to be positioned around the center of gravity of the aircraft. The three options available were to place a tank at either end of the fuselage, with passengers in the middle; a single tank in the center section under the wing, with passengers at either end; or a series of tanks arrayed linearly in the lower section of the fuselage under the passenger cabin. Although all three options place volatile fuel in close proximity to the passengers, it was

felt that the third option was the most practical. A system of four tanks was ultimately employed, with the aftmost tank extending into the tail cone. The fuel tank layout is depicted in Figure 12.1. To maintain trim during flight, a fuel transfer system would be used to shift fuel fore and aft accordingly.

FIGURE 12.1 FUEL TANK LAYOUT



The ram air or compressor bleed used to pressurize JP fuel tanks is also not possible with liquid methane. The tanks must be pressurized by some self contained system, such as gaseous helium. This was attractive as helium must be used to purge the fuel system of air before methane is introduced. A second option would be to reinject heated methane gas tapped from the supply

lines. A potential problem with this concept is that the gas may be cooled to the point of condensation, reducing the pressure in the tanks and aggravating the problem. The third possibility, which would be used by the Leading Edge 250 in combination with the initial helium pressurization, is to allow a controlled transfer of heat to the fuel from the outer surface of the aircraft. The control mechanism would be fuel circulating around the outside of the tanks before being delivered to the engines. This would also raise the temperature of the fuel towards the injection temperature required by the engines. Such a system would not force the aircraft to carry an additional tank or tanks to carry helium for the entire flight. A vent system would also be provided, which could include a cooled expansion tank to recover as much of the vented fuel as possible. The supply, transfer and vent systems would occupy the corners of the semicircular lower fuselage section on either side of elliptical main tanks (see Figure 12.1). Such a system, with cryogenic fuel, high pressure tanks, and pre-energized fuel more closely resembles that of a liquid fuel rocket engine than that of conventional aircraft. Figure 12.2 illustrates the general layout of the fuel system, although it should not be regarded as definitive. In actual operation the aircraft would have separate right and left hand systems with redundant power supplies and emergency backups such as a ram air turbine generator for the pumps.

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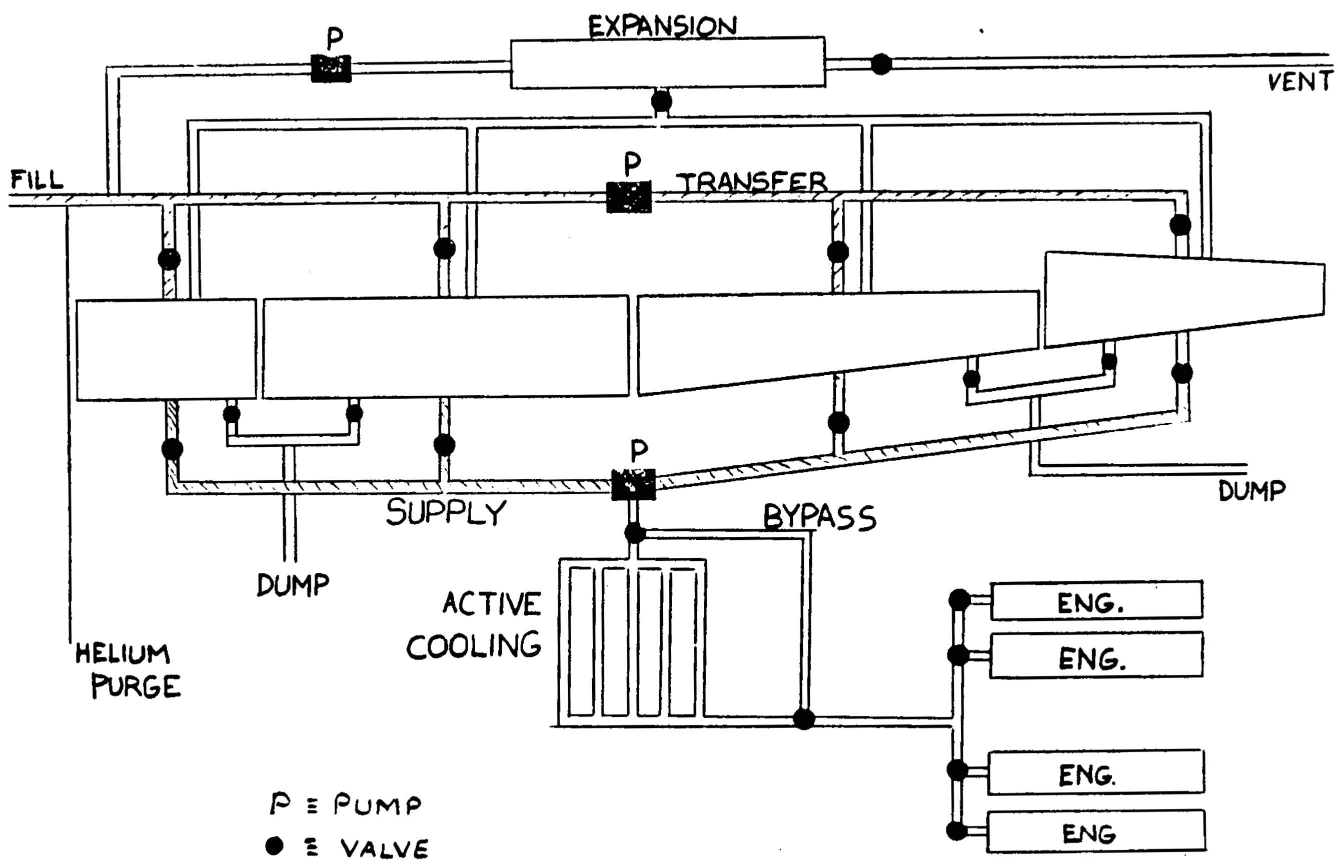
FIGURE 12.2 FUEL SYSTEM SCHEMATIC



12.2 HYDRAULIC SYSTEM

The hydraulic system of Leading Edge 250 is comprised of two completely independent systems. The system schematic is outlined in Figure 12.3. Each system is powered by two engines, therefor, even if three engines fail, the hydraulic system will still be operational.

In case of a complete power failure, the Leading Edge 250 is equipped with an auxiliary pump driven by an electric motor. This auxiliary pump will supply pressure to all the vital systems. These systems are:

Wing flap systems

Elevator systems

Rudder systems

Stability and stability augmentation systems

Nozzle systems

Thrust reverser systems (If used)

Inlet ramp actuators

Landing gears and doors

Steering

Brakes and anti-skid systems.

The hydraulic system of Leading Edge 250 is also equipped with an accumulator as a very last resort. In case of a complete power failure (engines as well as the auxiliary pump) it will provide temporary pressure to the landing gear and doors during emergency landing. The hydraulic system of Leading Edge 250 is very efficient and safe.

A general hydraulic layout plan is presented in Figure 12.4

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FIGURE 12.3 HYDRAULIC SYSTEM SCHEMATIC

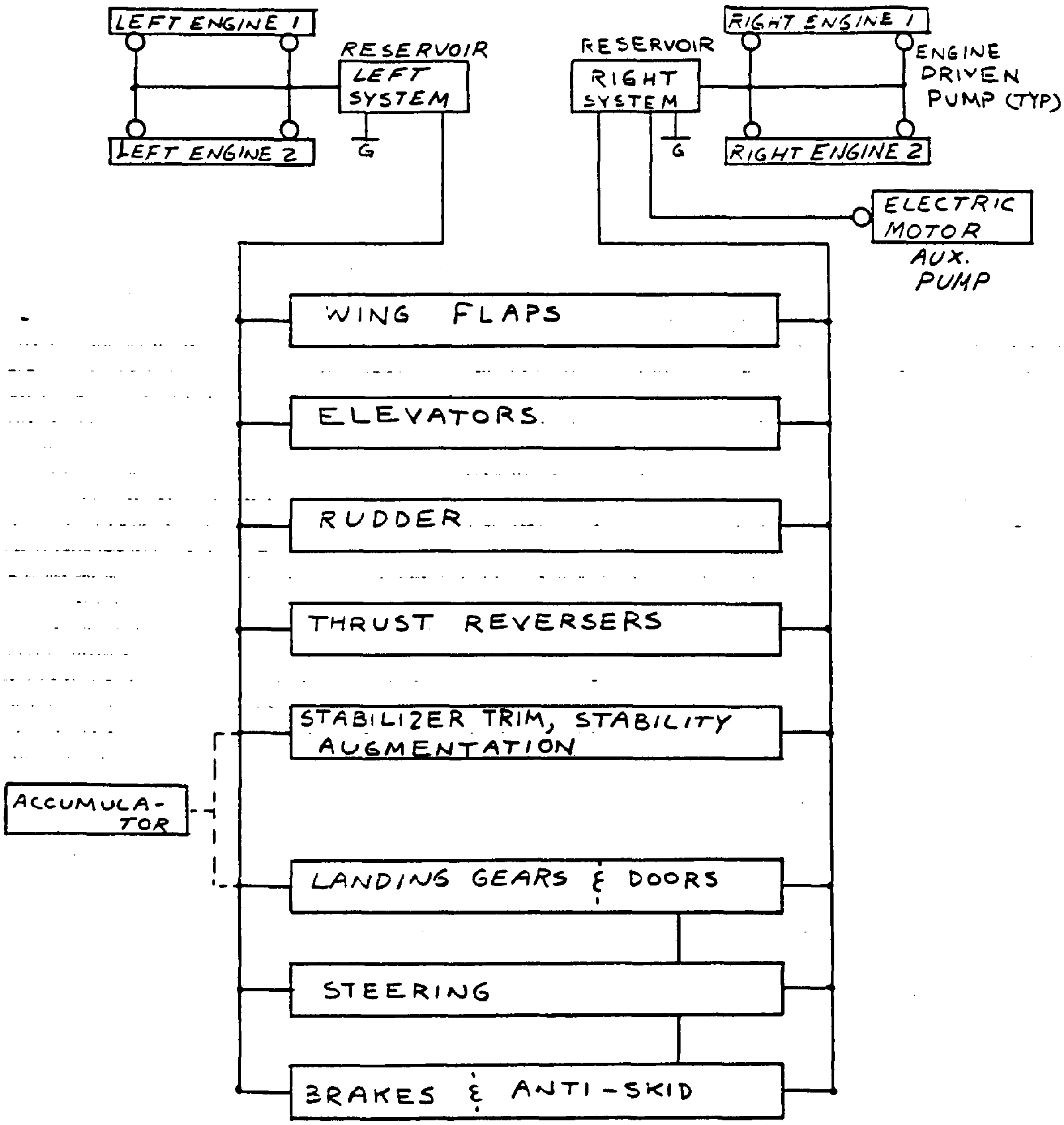
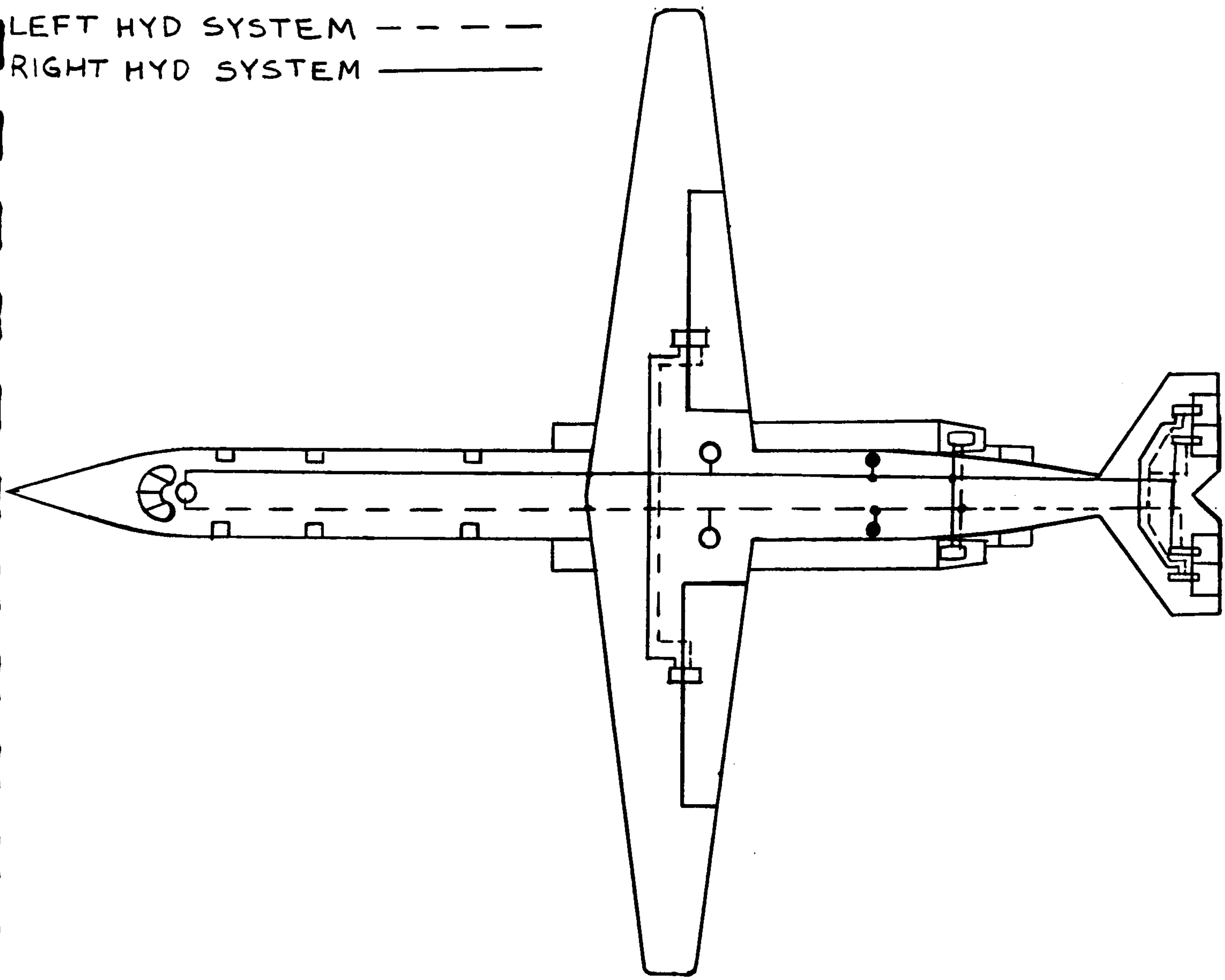


FIGURE 12.4 HYDRAULIC SYSTEM LAYOUT



13.0 COST

Cost estimates were performed using the RAND report for the USAF for estimating cost of aircraft. The current average salaries for engineering and production work were used. These costs do not include any profit allowance, which is usually 10 percent of the cost.

The breakdown of costs for prototypes and production aircraft is as follows:

The cost of developing two prototypes in millions is

Airframe	$ 281.6
Flight Test	$ 127.9
Engineering	$ 371.8
Tooling	$ 78.0
Manufacturing	$ 234.2
QA	$ 30.4
Material	$ 91.4
Total	$ 1,215.5

The average development cost per aircraft in millions is

Airframe	$ 1,568.3
Flight Test	$ 311.1
Engineering	$ 5,386.4
Tooling	$ 2,141.9
Manufacturing	$ 7,040.7
QA	$ 96.3
Material	$ 157.1
Total	$ 10,401.5

The production cost for 25 aircraft per aircraft in millions is

Engineering	$ 131.4
Tooling	$ 50.5
Manufacturing	$ 86.3
QA	$ 11.2
Material	$ 43.1
Total	$ 322.6

The average unit cost is 201.3 million dollars.

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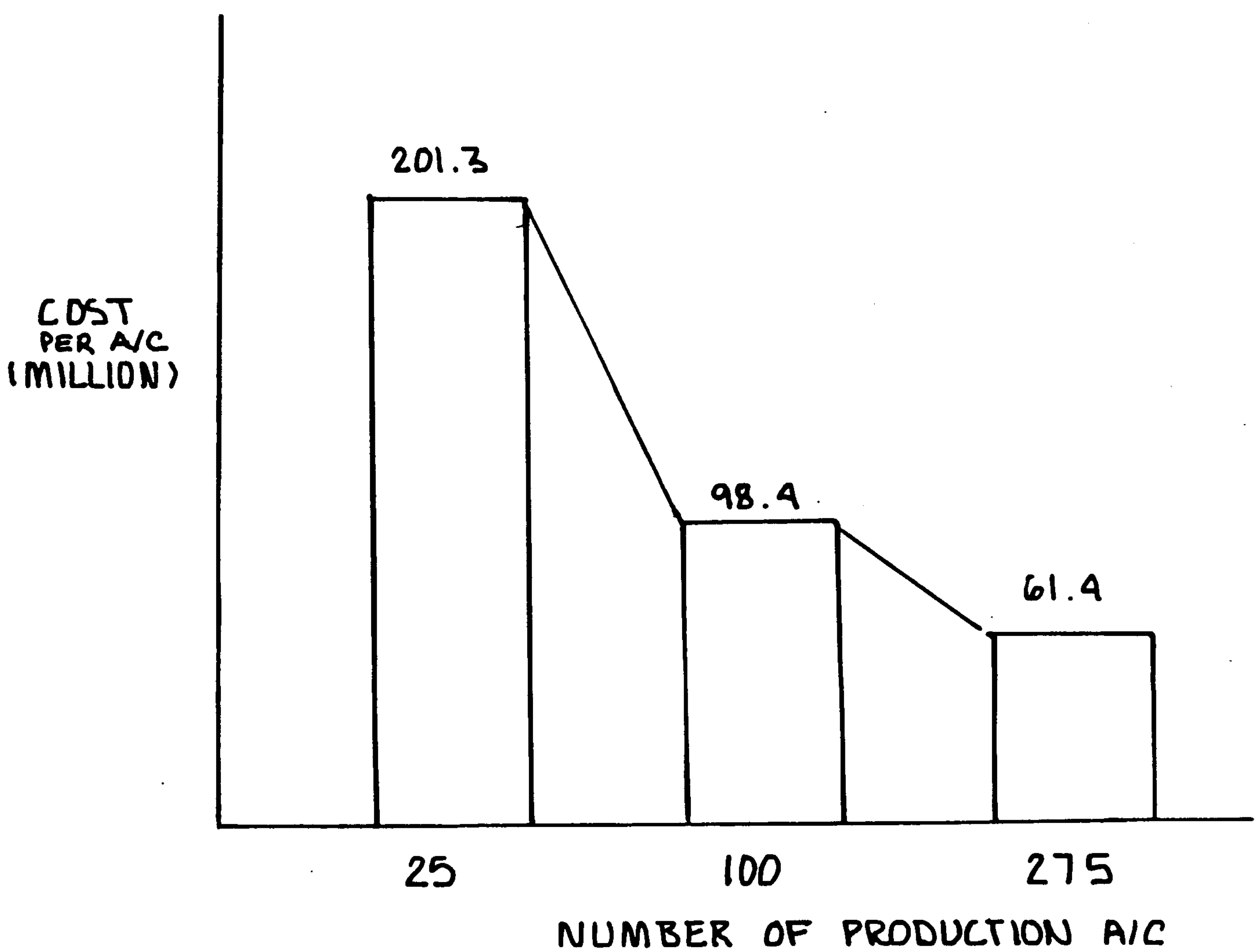
Figure 13.1 below shows the reduction in cost for additional production aircraft.

<u>FIGURE 13.1</u> COST REDUCTION FOR ADDITIONAL AIRCRAFT



14.0 CONCLUSIONS

The Leading Edge 250 High Speed Civil Transport has met all the requirements set forth in the RFP and the relevant sections of the FAR Part 25. The innovative design uses oblique wing technology to provide efficient aerodynamic characteristics in all flight regimes, from subsonic to supersonic speeds. Its propulsion system, using the wrap-around turbo ramjet, delivers optimum thrust at all Mach numbers throughout the aircraft's speed range. Though the expected average flight duration is only three hours, sufficient facilities have been provided for passenger comfort. And with all the new concepts and technology present in the design, the average cost per aircraft still remains reasonable.

Important features of the Leading Edge 250 are summarized below:

Performance:

- The Leading Edge 250 has a cruise Mach number of 4, but is capable of travelling at speeds up to Mach 5.
- Its range is 6,500 nautical miles with a maximum cruise altitude of 100,000 feet.
- Efficient flight is attained throughout mission profile due to mission adaptable oblique wing and wrap-around turbo ramjet.
- The takeoff and landing distances are less than existing runway lengths at most major airports, thus requiring no special runway facilities.
- Through use of titanium and steel alloy honeycomb structure, the aircraft can withstand the expected high operation temperatures without the use of active cooling.

Noise:

- Due to characteristics of the oblique wing, sonic boom intensity is less than that of other configurations at the same speed.

- Due to a higher climb rate, the leading Edge 250's noise footprint is smaller than many modern transports.

- Internal cabin noise is kept to a minimum since engines are located aft of the rear cabin bulkhead.

Cost:

- The cost of 25 production aircraft, per aircraft, is 201.3 million dollars, a reasonable amount.

Though the Leading Edge 250 is unconventional in design, it uses technology available today. With its ability to deliver passengers efficiently from Los Angeles to Europe within three hours, the design should become an attractive concept to all.

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